DEVELOPMENT OF VANE TESTING
EQUIPMENT FOR FOUNDATION
INVESTIGATIONS

DEVELOPMENT OF VANE TESTING EQUIPMENT FOR FOUNDATION INVESTIGATIONS

Submitted to the Faculty of

Rensselaer Polytechnic Institute, Troy, N. Y.

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for the degree of

Master of Civil Engineering

Submitted by:

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Troy, New York
26 May 1953

The Faculty
Rensselaer Polytechnic Institute
Troy, New York

Gentlemen:

It is with a feeling of deep gratitude for the knowledge and guidance you have bestowed upon us that we submit this thesis for your approval in partial fulfillment of the requirements for the degree of Master of Civil Engineering. We earnestly hope that the results of our work can be used to advantage by the Institute and that information contained herein will be of benefit to future investigators desiring to further develop the vane testing equipment.

We wish to take this opportunity to express our thanks to you for the spirit of friendliness and tolerance shown us during our course of instruction. We feel fortunate to have had the opportunity to study under your leadership.

Respectfully submitted,

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INTRODUCTION

It is the opinion of the writers that the shear strength of soil is an important consideration in foundation investigations, and that a means of obtaining usable shear strength data rapidly and easily should be developed. The usual laboratory methods of determining soil shear strength involve the removal of samples from various depths in the field, their transportation to a soil mechanics laboratory, preparation of these samples for the tests desired, conduction of the tests and compilation of results. This procedure may often prove to be relatively costly and time-consuming as well as at times rendering questionable results. The foregoing indicates a need for the development of some form of testing device which can be used in the field by the usual soil engineering staffs to supplement and, in some cases, replace laboratory shear tests. This function may be performed by penetrating the soil with a vane and rotating it, while the resistance to rotation is measured. The shear strength is then calculated from the maximum torsional moment.

The purpose of this thesis is to (1) study and present a summary of previous investigations, by others, of vane testing equipment, and (2) utilizing the results

of previous investigations, to design and manufacture a light-weight, compact, easily operated vane testing device for quickly obtaining the shear strength of soils in situ, and with this equipment to make such field investigations as time permitted. It should be stated here that the equipment mentioned is limited to use in relatively soft, fine-grained soils at depths of approximately thirty feet or less, and that it operates on a strain-controlled principle.

It is not intended that the above-mentioned equipment be considered a panacea of soil shear testing devices, but rather that it be considered an additional, and possibly useful, tool to be used in conjunction with other soils tests. Nor is there any intention in the following report to belittle the employment of currently accepted laboratory practices for determining soil shear strength. On the other hand, an attempt is made by the writers to, as clearly as possibly, present the history and theory concerning, design, fabrication, and use of the particular vane testing equipment developed by them, as well as to illustrate its practicability as compared to other shear testing apparatus.

Due to time limitations it was not possible to proceed, as originally desired, with certain phases of development, such as experimentation with various vane

shapes, etc.. However, this work, along with certain suggested improvements, are included under "Suggested Future Development and Studies", herein.

It is sincerely hoped that vane testing equipment, similar to that described in this thesis, might prove to be of valuable assistance in the solution of soil mechanics problems encountered by soils engineers and their staffs.

PRELIMINARY INVESTIGATIONS

(A) PREVIOUS INVESTIGATIONS

It was determined by the writers that as much information as possible should be obtained from previous investigations. The basis for this decision was two-fold, as indicated below.

The first, and main reason, for studying the work of others, was because of insufficient time to start completely new investigations on assumptions, theories, etc. for measuring the shear strength of soil with vane-type equipment. This study was made as carefully as possible in order to gather the proven theories and workable assumptions. As will be shown later, these assumptions were used by the writers to make it possible to complete their phase of the work. To reiterate, the purpose of this investigation was, not to prove the worthiness of the vane testing equipment, but to develop a simple workable tool with certain limitations.

Secondly, a study of these previous investigations was made to provide a summary for easy review by future investigators of applicable portions of certain past investigators' reports regarding this subject. It should be pointed out that the summary of past investigations

and the writers' short investigations presented by this report do not cover all required or desirable phases of investigations of this equipment. Suggested possible additional investigations will be covered later, but it can be mentioned here that it is the feeling of the writers that the equipment developed by them may readily be used, with minor alterations (see Design) in making these investigations as well as in actually evaluating soil strength problems.

The papers that will be summarized herein are:

(1) I. Evans and G. G. Sherratt, Army Operational Research Group, War Office, "A Simple and Convenient Instrument for Measuring The Shearing Resistance of Clay Soils", from the Journal of Scientific Instruments and Physics in Industry, Vol. 25, No. 12, December,1948.

(2) L. Cadling and S. Odenstad, "The Vane Borer, An Apparatus for Determining the Shear Strength of Clay Soils Directly in the Ground" from the Royal Swedish Geotechnical Institute Proceedings, No. 2, Stockholm, 1950.

(3) A.U. Skempton, "Vane Tests in the Alluvial Plain of the River Forth Near Grangemouth" from Geotechnique, Vol. I, No. 2,December,1948.

(1) Messrs. Evans' and Sherratts' report:

<u>Description of Equipment</u>: These investigators first developed a vane for field use. The report deals mainly, however, with the adaptation of this vane to a "Miniature Vane" which measures the "compressive strength" of a clay soil in the laboratory. A sketch of the instrument is shown in figure 1. The instrument is used as follows: "The vanes are coated with a thin film of oil and then wound down into a cylinder containing the soil sample until the topmost edges are $\frac{1}{2}$-1 inch below the surface. A torque is applied slowly and gradually increased in magnitude until the soil fails by plastic flow, indicated by a stationary reading of the pointer."

<u>Theory</u>: These investigators realized that the distribution of stress in the soil adjacent to the vanes is complicated. Rather than make a time-consuming analysis with the probable necessity of the use of many assumptions, they simplified the problem by making the overall assumption that failure takes place over the surfaces of the cylinder of revolution of the vanes. They then made calculations, based on this cylindrical surface of failure, for the shear strength. They found that the theoretical value exceeded the experimental value (unconfined compression test) by about 7%.

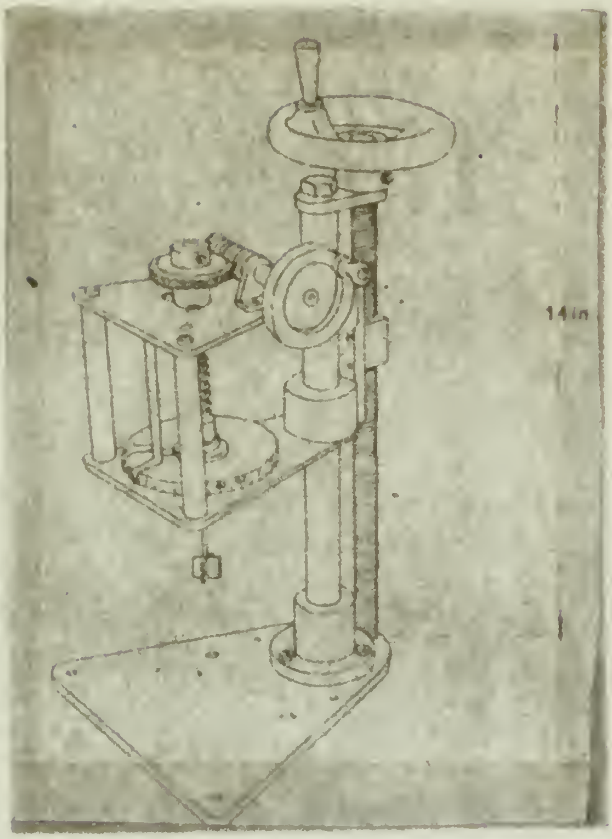


Diagram of Miniature Vane

FIGURE - 1

This theoretical value however did not take into consideration the "adhesion between the soil and the stem to which the vanes are attached". When they considered this item, their theoretical and experimental values were very close.

Results: Messrs. Evans and Sherratt discovered, with the use of their laboratory instrument, that the torque required to produce shear failure in the sample of clay had a straight-line relationship with compressive strength. This clay was assumed to have an internal angle of friction of zero. Cohesionless materials, on the other hand, were found to have a torque compressive strength relationship other than linear. An analysis was made and it was determined that this relationship was of the second order. These investigators also studied the effect produced by varying the rate of application of torque. The largest variation was determined at the slower rates of application, i.e., above 3.5 degrees per second rotation the variation was slight. The speed selected was 1/60 revolution per minute or 0.1 degree of rotation per second.

(2) Messrs. Cadling and Odenstad report:

<u>Description of Equipment</u>: This report is very comprehensive. It is highly recommended that any future investigators of this type equipment read this report. A brief summary of the more general aspects of their work is presented herein. These investigators developed two experimental apparatus. The first consisted of a vane of four thin rectangular wings welded to a shaft. This shaft extends upward through a bearing to a lever above a protractor table. A turning handle is mounted on the protractor table. There is no physical connection between the protractor and the shaft. At each end of the lever a spring balance is connected to the turning handle. The angle of rotation is then measured by the protractor and the torque by the spring balances.

The operation of the borer is as follows: "The borer is driven down into the ground by pressure or by ramming. (This consists of driving the casing and the vane at the same time.) Before driving the borer the turning handle, the uppermost coupling, and the parts attached to it are removed. In order to protect the vane during driving it is lifted, so that the wings rest against the lowermost coupling.

When a soil layer to be tested is reached, the parts which were removed are reassembled, and the vane is lowered to the testing position by pushing down the extension rod. The test is then carried out as follows. The turning handle is turned at such a speed that the rate of rotation of the lever is kept constant. This rate is checked by means of a watch and the readings on the protractor. The forces indicated by the spring balances are noted at certain definite time intervals, and when the maximum readings are recorded, the turning is stopped. If the remolded strength of the clay is to be measured, the turning handle is rotated much faster until the clay is completely remolded. The borer is then driven down to the depth where the next test is to be performed, and the procedure is repeated."

The second instrument was of a more refined nature using the same principles as the first instrument.

Theory: These investigators actually analyzed each assumption made. Their investigations include the following:

(a) Shape of the surface of failure. The investigators determined through actual visual observations, by

a unique method, that the surface of failure very closely resembled a cylindrical surface.

(b) Distribution of stresses. The results of the study are quoted herewith: "In shear test devices it is attempted to apply the stresses so that the stress distribution should be as uniform as possible, in order to avoid progressive failure of the sample. In a vane test progressive failure might be expected to start in front of the edge of each wing and to spread gradually across the whole surface of rupture....,Generally the deformation in front of each wing seems to be somewhat larger than behind it. The contrary, i.e., a deformation that is larger behind a wing can also be observed .....Usually, however, the deformation seems to be comparatively uniform across the whole surface of rupture. Hence it may be concluded that the progressive character of failure seems to be slight and does not appreciably affect the test results."

(c) Rate of Rotation. Messrs. Cadling and Odenstad determined, like Messrs. Evans and Sherratt, that 0.1 degree of rotation per second was the best rotation rate for accurate results. The selection of this particular angular speed was due to the fact that it gave the smallest shear strength. (See writers "Theory" for expansion of this subject.)

(d) Length of the vane shaft. It was recognized that as the investigators drove their borer into the clay it disturbed the clay ahead of it and around its perimeter. It was believed that the disturbance caused by the vane was very slight due to the thinness of the wings. (It might be noted here that Evans and Sherratt called these blades "vanes" and the above investigators called them "wings", with four wings assembled to make a "vane".) The disturbance caused by the casing, however, was considered to be of relatively large magnitude. By conducting tests, where different vane shafts were used, in which the vane was penetrated below the bottom of the casing, it was determined that a minimum length of five times the diameter of the boring should be used.

(e) Number of wings. It was felt that the number of wings might have an effect on the maximum torsional moment, i.e., the shear strength measurement. If too few wings were used the stress distribution on the surface of rupture might not be as uniform as in the case of a vane having a great number of wings. On the other hand, a large number of wings would tend to disturb the soil more while being penetrated, resulting in a smaller torsional moment. A few tests were

conducted to investigate this matter. It was determined that the four wing vane gave higher moments than the two wing vane. It was also found, and it is recognized intuitively, that the two wing vane in a strong soil tended to bend under the torsional moment. The four wing vane was therefore adopted by these investigators.

(f) Vane Dimensions. These investigators realized that at the moment of "rupture" the stress distribution of the clay over the walls of the cylinder was fairly well known, for the state of stress and the state of strain at any instant was the same throughout. Such, however, was not the case at the end surfaces of the cylinder, for the state of strain varies from the center of the vane outward to its perimeter. The assumption was made, however, that the stress distribution at these end surfaces was uniform. The investigators then proceeded to see what per cent of error this assumption produced. First it was determined that the error introduced was on the side of safety. (No explanation of this statement was made in the report.)

The writers of this paper have expanded on this point under "Theory". Secondly, by varying the ratio H/D (H = height of vane and D = diameter or width of vane) they determined the magnitude of the error. Their findings were:

H/D	Rate of Error
1	6.3
2	3.6
3	2.5

These investigators further recognized that the larger the ratio of H/D the larger would be the torsional moment required to produce "rupture". Therefore, the design of the vane shaft would be affected, i.e., the diameter. Since the smallest possible vane shaft diameter was considered desirable to minimize the disturbance effects, the ratio of H/D = 2 was adopted.

<u>Results</u>. The general shape of a moment curve determined by the investigators is:

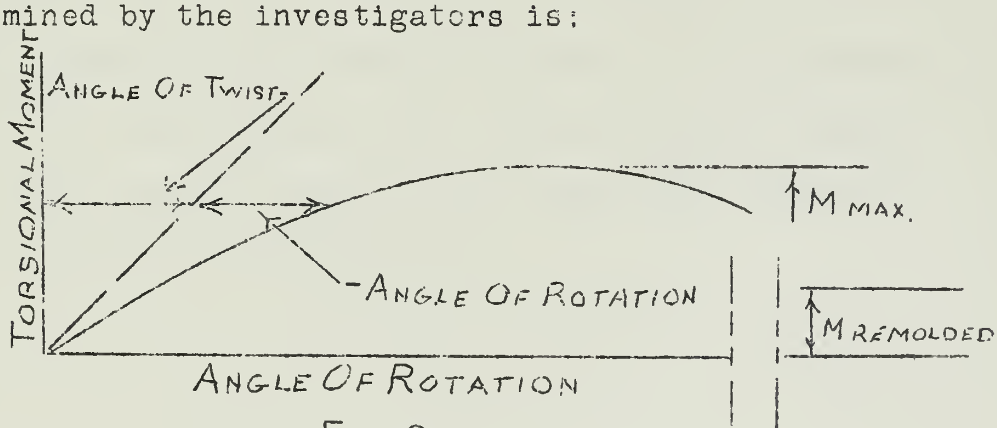


Fig. 2

"The curve rises with the angle of rotation, first rectilinearly, then gradually passing into a curved shape, and finally reaching a maximum value (M max.), after which it falls. If the rotation is continued, the clay is remolded, and the curve asympototically approaches a minimum value (M remolded)." They then determined the angle of twist of the torsion system experimentally for different depths. The horizontal distance, then, between the angle of twist of the system, and the moment curve, represents the angle of rotation of the vane. This angle, as described by the investigators, bears a definite relation to the angle of shearing strain in the clay, and may be used in determining the elastic qualities of the soil.

The investigators found that the vane strength values were in close agreement with the shear strength values calculated from eleven slides and one loading test. And that vane test results and unconfined compression test results seemed to agree at small depths, while the former exceeded the latter at great depths. Also that vane test results and "cone" test results were in fairly close agreement.

(3) Skempton Report:

Skempton's equipment was developed on the basis of using it in conjunction with the normal type of boring operations in which samples are taken. The apparatus consists of a vane --- "attached to a rod of high tensile steel $\frac{1}{2}$ inch in diameter which, at a distance of three feet above the vane, passes through a guide in which it can rotate freely. The top of the steel rod (vane shaft) then screws into a socket on $1\frac{1}{2}$ inch diameter tubing which extends up the borehole. At intervals of about thirty feet along this tubing, guides are arranged to provide vertical alignment. A torsion head, twenty inches in diameter, is attached to the top of the tubing, a thin wire passes around this head, then through a pulley fastened to a spring balance, and finally to a tennis net winder. By turning this winder, the torsion head, and hence the vane, is rotated; the tension in the wire is given by halving the spring balance reading. The rim of the torsion head is graduated in degrees and it is an easy matter to turn the winder at such a speed that the head rotates at a constant angular velocity."

Theory. This investigator used certain facts proven by previous investigators. However, certain new ideas were added by this paper.

All of these are briefly summarized here:

(a) Length of vane shaft. 5 d (same as the Swedish report where d is diameter of boring).

(b) Use of a "dummy rod". to obtain friction in the system and frictional drag by the soil on the vane shaft. (This item was not mentioned in the Swedish report, but was considered by Evans and Sherratt).

(c) Surface of rupture. "There is no reason to suppose that shear takes place along a cylindrical surface defined precisely by the radius of the vane. It must, therefore, be assumed that there is an 'effective diameter' equal to X · D, where X is a coefficient to be determined by calibration and D is the diameter of the vane". The value of X was found to be equal to 1.05.

(d) Rate of rotation. During the calibration tests mentioned above, various rates of rotation were tried, and similar rates of loading were used on unconfined compression tests on samples of the same material. It was found that the shear strength varied similarly in each type of test. The standard time of rotation, or loading, chosen was ten minutes.

Results. "The vane tests and unconfined compression tests on undisturbed samples were in close agreement to a depth of forty five feet. At greater depths, the vane gave increasing strengths while the sample remained essentially constant. At all depths the remolded strengths as measured by the vane were approximately equal to the values obtained by compression tests on remolded clay."

Summary of Previous Investigations. In order to select the assumptions and theories for which agreement existed among the three papers reviewed, the writers prepared a table of comparison (see Table 1).

(B) THEORY

As has been previously pointed out, most of the findings of the previous investigators were accepted and used in the particular investigations chosen by the writers of this thesis. Those findings that were adopted are listed in subsequent paragraphs. In some cases these findings were expanded upon by methods chosen by the writers.

Certain design criteria were required at the outset in order that a tentative design could be realized. These values, their derivation and the assumptions and theories used in the derivations are as follows:

TABLE OF COMPARISON

ITEM	EVANS AND SHERRATT	CADLING AND ODENSTAD	SKEMPTON
Shape of the surface of failure	Assumed cylindrical	Ran tests to show that it was very close to cylindrical	Assumed cylindrical where effective diameter of cylinder equals XD. D equals diameter of vane; X equals coefficient determined by calibration.
Distribution of stresses	Assumed uniform over all surfaces	Assumed uniform over all surfaces	Assumed uniform over all surfaces
Rate of rotation	6 degrees per minute	6 degrees per minute	Approximately 6 degrees per minute
Depth of vane shaft penetration into undisturbed soil	Unknown	5 d*	5 d *
Number of wings on the vane	Four	Four	Four
Vane Dimensions	Unknown	H/D* equals 2	H/D * equals 2
Vane results vs. unconfined compression test results	Unknown	At small depths under 45 feet-very close. Over 45 feet - Vane results larger	Similar to Cadling and Odenstad

5 d* (d equals diameter of boring)
H/D* (H equals Height of vane
(D equals Diameter of vane)

TABLE - 1

(1) Torsional Moment: To obtain an equation for this moment a knowledge of surface of rupture, strength of soil, stress distribution and vane dimensions is required.

The surface of rupture is assumed to be a cylinder of the same diameter and height as the vane. It is felt that other investigators have proved conclusively that the actual failure surface is very close to that of a cylinder.

Strength of soil: At the outset it was decided to develop an instrument which could measure the shear strength of soft cohesive soils with a maximum shear strength of 1500 pounds per square foot.

The Stress distribution is assumed by the writers to be uniform over all surfaces of failure. It has been stated by previous investigators that this assumption produces an error which is on the side of safety. It is intended by the writers to prove that statement.

If the Vane dimensions are taken at H/D equals 2, where H is the height of vane and D the diameter, then the surface area over which the strength of the soil will tend to resist the torsional moment will be equal to $2\pi D^2 + \frac{\pi D^2}{2}$.

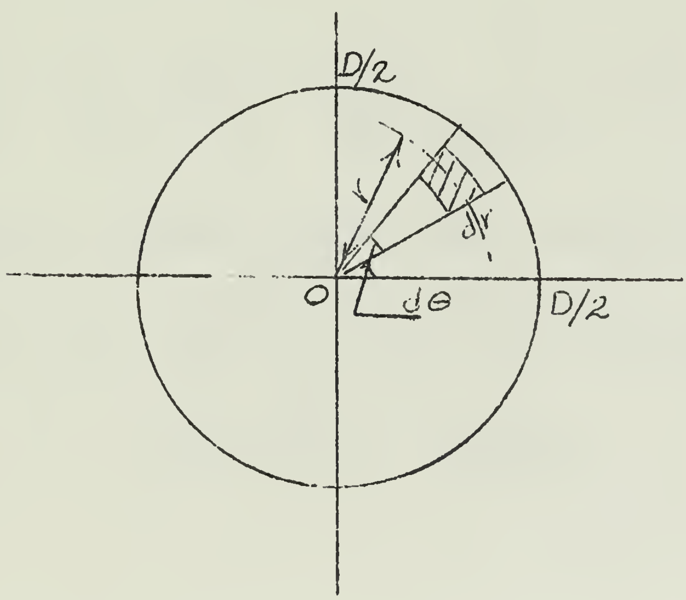
Where the first term represents the cylinder wall surface and the second the surface of the top and bottom which are circular, the moment required to overcome shear stress is:

(a) On the cylinder wall M_1 equals $2\pi D^2 \cdot S \cdot \frac{D}{2}$

Where S equals shear strength resisting torsional moment and D/2 is the moment arm.

Therefore $M_1 = \pi D^3 S$

(b) On the top and bottom surfaces the moment calculation is made more complicated by the fact that the moment arms vary from zero at the center of rotation to D/2 at the wall surface of the cylinder. The solution of this problem is more easily seen by the use of a sketch of a differential element as seen below.



By constructing a wedge whose central angle $d\theta = 1°$ and producing a differential element as seen crosshatched above, it is possible to obtain the total moment required to overcome the shear strength developed in the differential element. It is necessary to keep in mind that the unit stress is considered to be uniform from 0 to D/2.

$$M_2' = A \cdot X \cdot S$$

Let:

M_2' = Moment over a differential element

A = Area of differential element (cross-hatched)

X = Moment arm from center of rotation to center of differential element.

S = Shear strength of soil

Then:

$A = dr \cdot rd\theta$

$X = r$

$\therefore M_2' = dr \cdot rd\theta \cdot r \cdot S = dr \cdot r^2 \cdot d\theta \cdot S$

But: $d\theta = 1° = \frac{\pi}{180}$ radians

Let: M_2 = Total moment over a circular section

$$\text{Then: } M_2 = 360 \int_0^{D/2} M_2' = 2\pi S \int_0^{D/2} r^2 dr = 2\pi S \left[\frac{r^3}{3} \right]_0^{D/2}$$

$$= 2\pi S \cdot \frac{\frac{D^3}{8}}{3} = \frac{\pi D^3 S}{12}$$

The total moment (M) then for the entire cylindrical surface is:

$$M = 2 \cdot \frac{\pi D^3 S}{12} + \pi D^3 S$$

$$= 7/6 \pi D^3 S$$

It is intended to limit the use of various size vanes to certain strength ranges of soil (see "Design").

The three inch vane has been selected to be used for the maximum range of 1500 pounds per square foot. The maximum torsional moment is:

$$M = 7/6 \pi 3^3 \cdot \frac{1500}{144} = \underline{\underline{1030}} \text{ in. lbs.}$$

It was stated by the Swedish report that the above moment based on uniform stress distribution gives results which are on the side of safety.

This statement is verified below.

If the unit shearing stress of the soil is now assumed to vary linearly from S at the perimeter to zero at the center of the top and bottom circular surfaces, and remains constant over the wall surfaces, the moment required to produce shear failure is developed as follows:

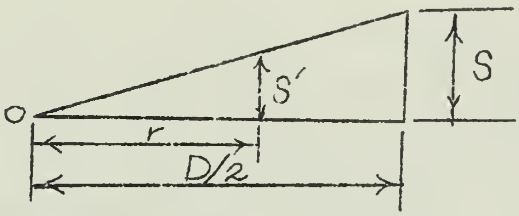
Again the above sketch of the differential element should be referred to.

M_2' = Area of the differential element X moment arm X the average shear stress across the element.

Area = $dr \cdot rd\theta$

Moment Arm = r

Shear stress: This stress is assumed to vary linearly from zero at the center to S at the perimeter of the circle.



The above sketch represents this linear stress variation. And S' represents the average stress across the differential element.

$$\therefore S' = \frac{2\,S\,r}{D}$$

$$\therefore M_2' = dr \cdot rd\,\theta \cdot r \cdot \frac{2Sr}{D} = \frac{2Sr^3}{D} \cdot dr \cdot d\theta$$

Total Moment over the circular area

$$= \int_0^{D/2} M_2''$$

$$= \frac{4\pi S}{D} \int_0^{D/2} r^3\,dr = \frac{4\pi S}{D}\left[\frac{r^4}{4}\right]_0^{D/2} = \frac{4\pi S}{D} \cdot \frac{D^4/16}{4}$$

$$= \frac{\pi S}{16} D^3$$

Total Moment over entire surface $= \pi D^3 S + \frac{2\pi D^3 S}{16}$

$$= 9/8\pi D^3 S$$

It can also be shown that the constant represented by $9/8\pi$ or $7/6\pi$ will vary depending on the type of stress distribution across the end surfaces and that all types of stress distribution produce constants which are less then $7/6\pi$.
The resulting shear strength, therefore, from a measured torsional moment will always yield the smallest value by using $7/6\pi$ as the constant. This can be seen analytically as follows:

$$M = K D^3 S$$

Where K is a constant depending on the type of stress distribution.

$$\therefore S = \frac{M}{K D^3}$$

K with the largest value will give the smallest value for the shearing strength. This is on the side of safety.

(2) Vane Dimensions: The value of H/D equals 2, indicated as the best by Cadling and Odenstad, has been selected for this design. Vane diameters of 3" and 4" will be fabricated.

(3) Depth of penetration of the vane: The depth of 5 d chosen by previous investigators is used. It is assumed that the maximum casing inside diameter will be 6". The depth of penetration of the vane into undisturbed soil is then 30".

(4) Rate of rotation: A value of 0.1 degree per second is used. This value has proven to produce accurate results by previous investigators.

The section of the Swedish report dealing with rate of rotation has been given additional study by the writers, and is herewith expanded upon to further substantiate the use of the above rate of rotation.

A study of all rotation produced during a vane test is necessary to analyze the problem. Since a vane test is accomplished by rotating the upper end of a shaft which end is some distance above the vane, there is considerable rotation in the shaft, especially at the beginning of the test. Because of this twisting of the shaft, the initial rate of rotation of the vane is less than the upper end of the shaft. The rate of rotation of the vane, however, increases during the last and most important stage of the test until it equals the rate of rotation of the shaft. In order to investigate the effect of this nonuniform rate of strain,

several tests using various rates of rotation were made by Cadling and Odenstad. A study of their results yields the following type curve.

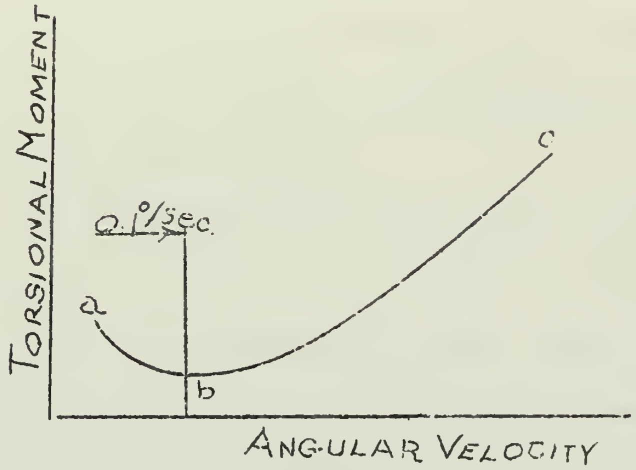


FIG. 3

It was determined that at very low speeds the soil actually consolidated, and that as the speed was increased the torsional moment required to produce rupture decreased, portion a-b of the above curve. Greater speeds, however, produced higher torsional moments, from b to c. A minimum point was therefore observed. The angular velocity at this point (b) was 0.1 degree per second. It is therefore seen that any other speed gives shear strength values which will be on the unsafe side.

(5) Total strain required to produce failure: It has been stated that the total rotation will include

the twist in the shaft and the rotation (or strain) of the vane in the soil. Calculation of the total angle of rotation for the limits of the vane equipment developed by the writers was necessary in the design of the equipment. The problem was approached in the following manner:

(a) By assuming the required angular strain (rotation of vane) over the range of soil strengths from 0 to 1500 pounds per square foot, or more specifically for the range of torsional moments corresponding to the above shear strengths, i.e. 0 to 1030 inch pounds. Tests conducted by previous investigators were used in making this assumption.

(b) By calculating the twist in the shaft for the worst possible condition. This twist varies with the length of the shaft (depth of vane) and strength of soil (torsional moment). The worst possible condition is the maximum depth at the maximum soil strength.

The angle of twist of a 30 foot shaft is computed as follows:

$$\emptyset = \frac{32\ Mt\ l}{\pi\ (d_o^4 - d_i^4)G}$$

$\emptyset$ = angle of twist

l = length of shaft=30 X 12 = 360"

G = modulus of elasticity in shear=4×10^6

M_t= torsional moment

d_o= outside diameter

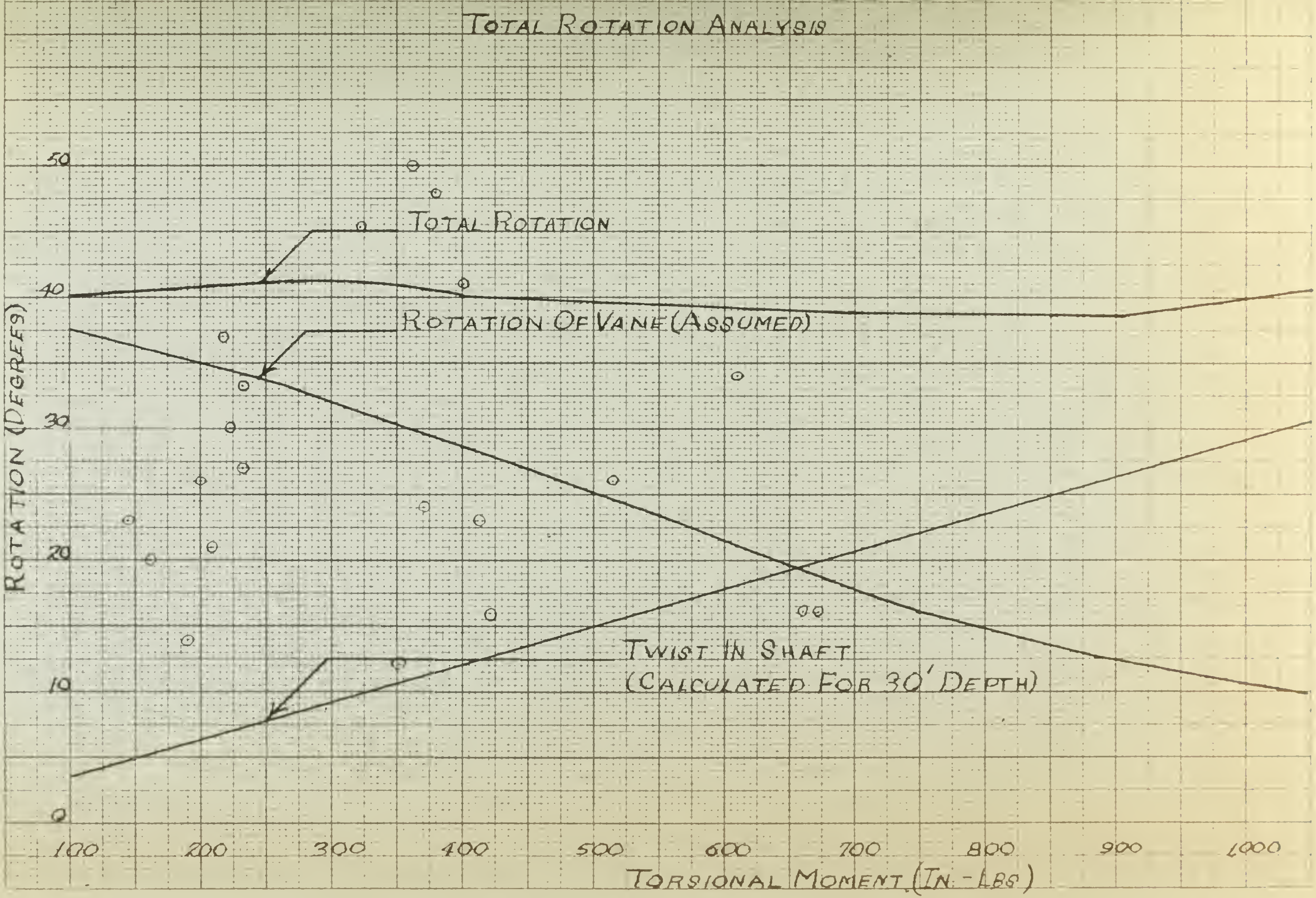
d_i= inside diameter

$$\therefore \phi = \frac{(32)\ (1030)\ (30 \times 12)}{(3.14)\ \left[(1.315)^4 - (1.049)^4\right] \times 4 \times 10^6} =$$

0.532 radians

= 30.4 degrees

(c) By then combining the rotation of the vane and twist of the shaft to obtain the total rotation as follows: (See Figure 4). Assuming a depth of 30 feet, the twist of the shaft was plotted with degrees of rotation versus torsional moment. The rotation of the vane curve was plotted using the same coordinate system based on the assumption that low strength soils undergo large strains before failing in shear due to their high plasticity and that, as the soil strengths increases, the amount of strain preceding failure decreases. It was felt that this variation was not linear (see curve). The ordinates of the rotation of vane and twist in shaft curves are added to provide the total rotation curve. From the latter curve it can be seen that the largest angle of rotation is about 41 degrees. To allow for additional slippage and rotation beyond the point of failure a total angular



TOTAL ROTATION ANALYSIS
TOTAL ROTATION
ROTATION OF VANE (ASSUMED)
TWIST IN SHAFT
(CALCULATED FOR 30' DEPTH)
ROTATION (DEGREES)
0
10
20
30
40
50
100
200
300
400
500
600
700
800
900
1000
TORSIONAL MOMENT (IN.-LBS)

rotation for design of 45 degrees was chosen.

(C) DETERMINATION OF SHEAR STRENGTH

From section (B) Theory it was determined that the shear strength of the soil was:

$$S = \frac{M}{K\,D^3}$$

Where: S = Shear strength

M = Torsional moment at shear failure in inch-pounds

D = Diameter of Vane in inches

K = Constant depending on stress distribution assumption.

Now let: $\frac{K_1}{K\,D^3} = C_2,\ C_3,\ C_4,$ etc.

Where: K_1 = Constant to convert appropriate units to feet.

$C_2, C_3, C_4,$ = Constants for various size vanes i.e. C_2 = Constant for 2" vane, where 2" is the diameter of the vane.

Then: S = M(Appropriate Constant) = Lbs./Sq.Ft.

Evaluation of Constants:

$$C_2 = \frac{144}{7/6\,\pi(2^3)} = 4.93$$

$$C_3 = \frac{144}{7/6\,\pi(3^3)} = 1.455$$

$$C_4 = \frac{144}{7/6\,\pi(4^3)} = 0.614$$

(D) CONCLUSIONS

The theories developed and assumptions which were proven by previous investigations to be satisfactory have been accepted and used by the writers of this thesis. Certain statements concerning assumptions and theories have been expanded upon by the writers.

A summary of these items is as follows:

1. That the surface of rupture is a cylinder with the same height and diameter as the vane.

2. That the distribution of stresses is uniform over all surfaces.

3. The rate of rotation should be 0.1 degree per second.

4. That the vane should be penetrated 30 inches into undisturbed soil.

5. That the number of wings or blades on the vane should be four, and rectangular in shape.

6. That the ratio of height to diameter of the vane should be two.

In addition to the above-mentioned items it was felt that a dummy rod should be used to ascertain the amount of friction in the system and adhesion between the vane shaft and the soil, or, in other words to obtain a tare reading. Although dummy rods were not used by all investigators whose reports were studied by the writers, it is considered important to use a tare reading value in shear strength calculations, particularly when some of these readings represent a substantial percentage of the gross reading.

DESIGN

(A) DESIGN CRITERIA

The following criteria were used by the writers in designing the vane testing equipment; for a discussion of assumptions, and computations upon which these criteria are based, see "Preliminary Investigations, Theory":

(1) Maximum torsional moment to produce rupture-1030 in.lbs. (based on maximum shear strength of 1500 lbs./sq.ft. and 3"vane)

(2) Vane dimensions ($\frac{H}{D} = \frac{\text{height}}{\text{width}} = 2$) -- 3" x 6" and 4" x 8"

(3) Depth of vane shaft penetration into undisturbed soil (including vane) -- 30 inches

(4) Rate of rotation -- 0.1° / sec (or 6° / min.)

(5) Total strain (twist of pipe shaft and rotation of vane) to produce failure -- 45°

(B) DESIGN OF COMPONENT PARTS

(1) Vane and Shaft -- Since the vane is the shearing device and its size and shape determine the shearing surface, little deviation was made in its design from that of previous investigators. The 3" vane is formed by interlocking two 3" x 6" x 1/8" cold-rolled steel plates, (half-slotted with the long

dimension), thrusting the interlocked plates into a slotted $1\frac{1}{2}$" diameter solid steel shaft 5" long, and tack braising the assembled vane and shaft at the intersection of the vane plates, and at the shaft and vane connection. The solid shaft is then butted up to a section of 1" aluminum pipe (design described later) and coupled to it by means of a standard pipe coupling. This section of pipe is topped by a 1" female air hose quick coupling (also described later). A drawing of this vane and shaft assembly, which is 36" long including the vane, is shown by Figure 5 and Figure 5--A.

(2) Pipe -- In the design of a shaft to transmit the torsional moment from the vane to the measuring apparatus, it was necessary to compute the working shear stress which would be produced in the pipe shaft by the maximum torsional (twisting) moment in order that a suitable pipe size and material might be selected. Since a hollow pipe, rather than a solid shaft, was considered most practical because of its lower weight for the same strength, the following computations were made based on 1" pipe:

$$S = \frac{16M_t}{\pi d_o^3 \left(1 - \frac{d_i^4}{d_o^4}\right)}$$

S = Max. shear stress (unknown)

M_t = Max. torsional moment (in.-lbs.) = 1030 in.lbs.

d_o = outside diameter 1" pipe (inches) = 1.315"

d_i = inside diameter 1" pipe (inches) = 1.049"

$$S = \frac{(16)\quad(1030)}{(3.14)\quad(1.315)^3 \left[1 - \frac{(1.049)^4}{(1.315)^4}\right]} = 9260 \text{ p.s.i.}$$

The following was provided by tables in various handbooks:

Type of Material	Nom. Size	Wt./ft.	Allowable Shear Stress (p.s.i.)	Actual Working Stress (p.s.i.)
Gal. steel (ASTM 120) pipe	1"	1.68 lbs.	10,800	9,260
Aluminum (61ST-6) pipe	1"	.58 lbs.	30,000	9,260
Aluminum (round tubing 24S-T)	1"	.175 lbs.	41,000	35,100

The 1" galvanized steel pipe would have had sufficient shear strength, but 1" aluminum pipe was finally selected because of its lighter weight for the same size and consequent ease in handling. Although aluminum tubing is even lighter, its use was rejected because of fabrication difficulties expected from its use.

(3) Couplings -- At first it was decided to use standard pipe couplings to join the various sections of pipe, but, because of expected excessive wear of the aluminum pipe from wrench action and time involved in the use of ordinary couplings, it was determined that air hose quick couplings be used. These offered the advantage that the pipe could then be quickly coupled and uncoupled by hand, which was originally considered particularly desirable when moving from one hole to another previously-prepared hole or when using the dummy (tare) rod alternately with the vane. Another advantage is that the pipe can be turned up tightly in this type of coupling which, along with positive coupling-to-coupling contact, practically eliminates twisting losses at the couplings. With standard couplings, the pipe sections must be butted against each other in the coupling to

prevent turning when a torsional moment is applied, which would make the coupling process long and tedious. Pins may be used with standard couplings, but their use would necessitate an extra step in the coupling process. A hinged detachable joint with a sliding collar for rigidity was also considered, but was abandoned because of the necessity for special manufacturing of a non-standard hinge and because of expected difficulties in joining steel to aluminum. A cross-section of a typical coupling and pipe connection used in this thesis is provided by Figure 5 and Figure 5 -- B. The ability of the quick couplings to withstand the maximum torsional moment was determined by testing two sets of 3/4" air hose quick couplings in a torsion machine at a load of 2000 inch lbs.

(4) Bearing, Bearing Plate, and Shaft -- A means of centering the pipe shaft in auger holes or in drive pipe casings, and reducing friction to a minimum is afforded by a flange type ball bearing mounted on a small plate. This bearing plate is attached, during a test, to the strain plate (described later) which is in turn mounted on a 10" long section of 4" drive pipe (described later). A solid shaft is held in the bearing race by a self-locking collar.

At the top of this shaft a large hex nut is screwed on to a stud which has been screwed into a drilled and tapped hole. This shaft is coupled at its lower end to a short piece of 1" wrought iron pipe capped by an air hose quick coupling. This coupling, which is used to join the vane and shaft assembly to the measuring device assembly, is approximately at ground level for uncased holes, and at the top of the casing for cased holes. Details of the bearing assembly are shown in Figure 5 and Figure 5 -- F.

(5) Modification of Torque Wrench -- Several means of measuring the amount of torque applied to produce strain and shear were considered. The use of a torque wheel of approximately 20" diameter, rotated by gears through a worm gear arrangement by means of a hand-crank, was given some thought. However, a light-weight wheel of the desired size was not readily available in standard stocks. Also, the torque wheel assembly necessitated the use of a spring balance, or some similar device, to measure the applied torque. The writers were unable to find locally a suitable commerically-produced balance which would provide the sensitivity desired

and still cover the range required. Hence the use of a torque wheel was considered not feasible. Instead it was decided to modify a torque wrench to measure both torsional moment and strain. The torque wrench selected (see Figure 5 and 5 -- E for details) is described as follows:

(a) The vertical shaft portion of the torque wrench is connected through a square head to an ordinary wrench socket.

(b) At the top of this shaft is mounted, as an integral part of it, a $10\frac{1}{2}$" pointer which runs horizontally and terminates over a graduated scale at the free end of the torque wrench.

(c) A heavy steel leaf type spring is attached at the vertical shaft just below the pointer, It has the above-mentioned scale attached to it near its free end and its movement is separate from that of the pointer.

(d) As a force is applied to the free end of the torque wrench spring, the spring bends as a cantilever and its displacement with respect to the pointer is a measure of the torque applied.

(c) Since the pointer is attached rigidly to the vertical shaft of the torque wrench, its movement is a direct indication of the rotation of the shaft, and thus the vane.

Although the torque wrench, as purchased, had the desired capacity, its scale could not be read to the required degree of accuracy. To overcome this shortcoming, an extensometer with a 1" total plunger travel was used. Its dial casing is mounted on the spring portion of the torque wrench and the plunger placed in contact with the pointer under no load conditions. When the torque wrench is operated, the extensometer dial registers the applied torque to about the nearest 1.2 in. lbs. It is not important to know the exact number of lbs./sq.ft. represented by each unit on the dial since the torque wrench calibration curves, shown under "Preparation and Use of Equipment", are sufficient for obtaining the final shear strength value for each test.

In addition, a needle is attached to the pointer a short distance toward the vertical shaft end from the dial. Its movement over the protractor scale inscribed on the strain plate is a measure of the strain, i.e. rotation of the vane.

(6) Torque Wrench Carrying Case -- Because of the relatively fragile nature of the torque wrench, extensometer and strain needle, a carrying case was built for the torque wrench assembly. Details are shown in Figure 5 -- E.

(7) Ready-bolt -- A review of previous investigations indicated that the vane should be rotated at a constant speed of about 0.1° per second (or 6° per minute). Any device to which a constant rate of rotation might be applied, such as a hand winch, would have been suitable. The writers chose to use a 3/4" diameter bolt with a thread pitch which provided for ten turns per inch of travel. This bolt is mounted in two stationary hex-nuts and is turned by means of a hand crank braised to it at its free end. The bolt, which is rounded at the forward end, is turned slowly by means of the crank and forced against a 1" x 6" polished steel plate attached to the free end of the torque wrench. This action provides the force which produces the torsional moment in the vane shaft. The rate of rotation of the handle, considering the position of the applied force with respect to the center of the vane shaft, is one turn every four seconds.

The relative position of the ready bolt is shown in Figure 5. Details of its fabrication are provided by Figure 5 -- C.

(8) Strain Plate and Pipe Stand -- A 19" x 16" x 1/4" aluminum plate, termed the strain plate, is mounted horizontally on the 10" section of drive pipe mentioned in (4) above. The protractor scale inscribed on it is used, as indicated in (5) above, to measure the amount of strain produced by a given stress. In order to be sure that the length of this scale would be sufficient, three factors had to be considered:

(a) The actual total rotation of the vane before shear occurred.

(b) Lost motion in twisting due to taking up slack in the system (caused by loose joints or other connections).

(c) The angle of twist of the aluminum shaft.

The total rotation of the vane to produce shear was estimated at about 45 degrees. Lost motion due to possible non-positive contact at joints was considered negligible. The angle of twist of the shaft was calculated for maximum depth and for the maximum torsional moment expected (see <u>Preliminary</u>

Investigations, Theory). Therefore, the strain plate, and ready-bolt were designed on the basis of 45 degrees total shaft and vane rotation. The strain plate also serves as a base for the bearing plate and for the ready-bolt assembly. See Figure 5 and 5 -- D for details concerning this plate.

(9) Base Plate and Anchors -- To support the strain plate and 4" D pipe stand a 3' x 3' plywood base is provided for auger holes, i.e. when the stand is not coupled to a drive pipe casing. The strain plate and pipe stand is connected to the base plate at a flange in the center of the latter. In order to keep the base plate from rotating due to the force transmitted to it through the ready bolt assembly, strain plate and stand, ½" round steel anchors are driven approximately 2' into the ground (usually by weight of one's body). Folding ½" round steel handles are installed at two opposite edges of the base plate to facilitate moving the entire above-ground assembly and tools from one hole to another. For details of base plate fabrication see Figure 5.

(10) Carrying Case -- As stated in the purpose it was intended to design a compact soil shear testing unit. A carrying case, which contains storage space for the strain plate and pipe stand torque wrench and case, ready bolt, all vanes, anchors, dummy vane, short pipe sections and tools, was designed and manufactured as shown in Figure 6.

(11) Dummy Vane -- It is apparent that the results obtained from the vane alone cannot be used directly. Certain friction losses due to binding of the shaft in the pipe, adherence of soil to the buried portion of the shaft, etc. have to be considered. Thus a dummy rod, which consists of a vane and shaft assembly minus the vane blades, was designed to be thrust into the soil (in conjunction with vane tests) and rotated to obtain a tare reading which is subtracted from the vane test maximum reading.

(C) DESCRIPTION OF COMPLETE EQUIPMENT

(1) Drawings -- A general layout of the equipment, ready for testing, is provided by Figure 5. Details of individual component parts are shown in Figures -- 5 A to F. Carrying case dimensions are given by Figure 6.

(2) Bill of Materials -- see Table 2.

(3) Principles of Operation -- The vane testing equipment described in this thesis is designed to operate as follows: (refer to Figure 5):

(a) The vane, which is imbedded 30" in undisturbed soil, is rotated clockwise in the soil by the action of the ready-bolt thrusting against the torque wrench.

(b) The reaction of the soil against the vane blades produces a moment which resists (counter-clockwise) the vane turning moment.

(c) This resisting moment is transmitted through the vane shaft, pipe shaft and couplings to the torque wrench.

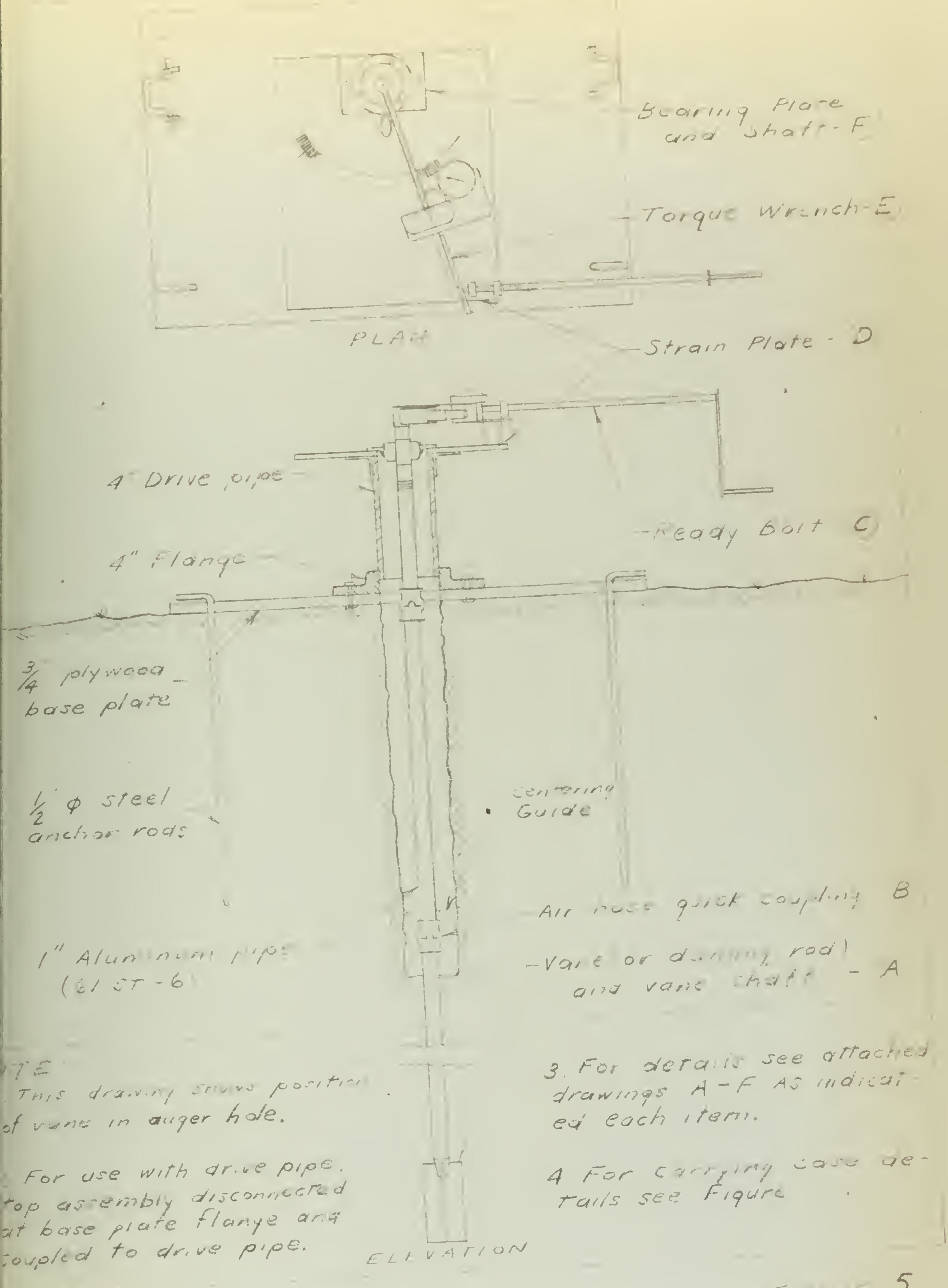
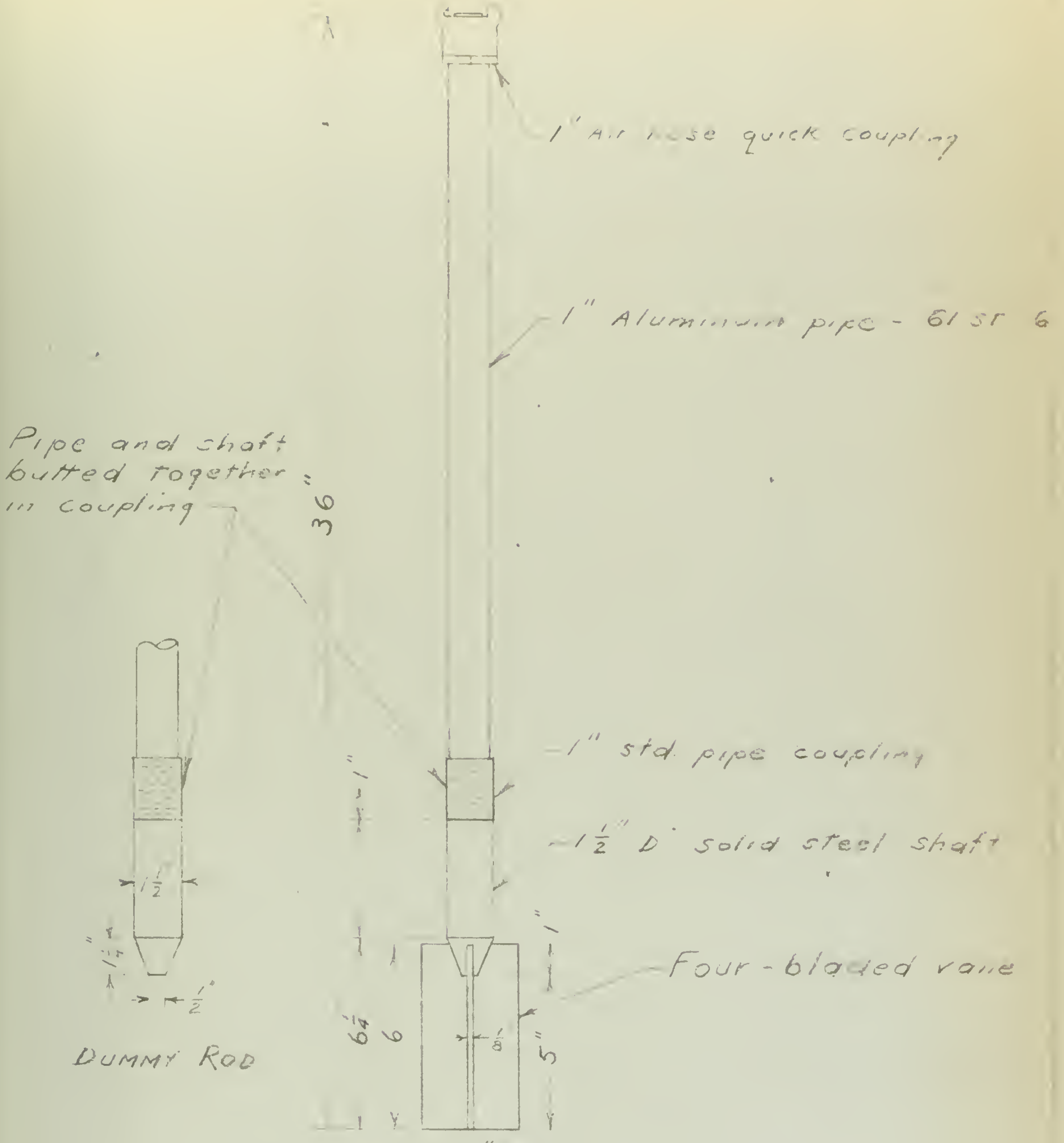
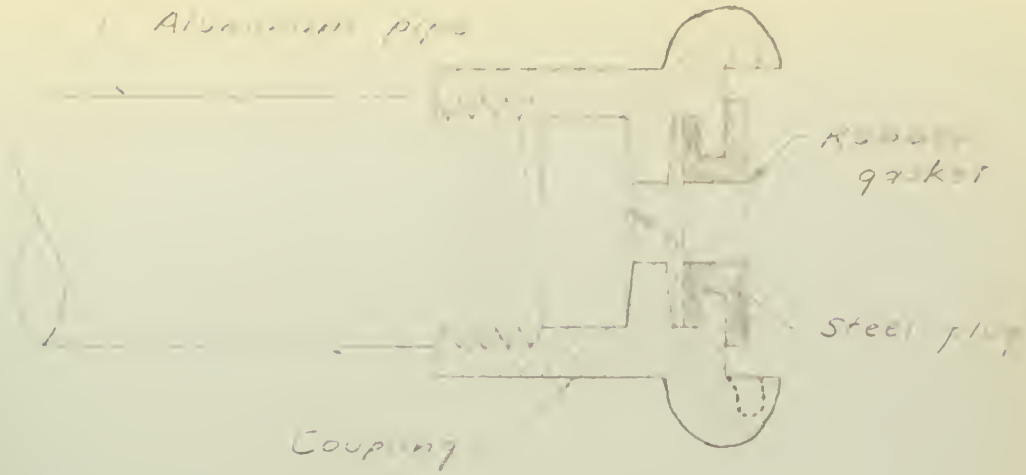

Bearing Plate and Shaft - F
Torque Wrench - E
PLAN
Strain Plate - D
4" Drive pipe
Ready Bolt C
4" Flange
3/4 plywood base plate
1/2 φ steel anchor rods
Centering Guide
Air hose quick coupling B
1" Aluminum pipe (61 ST-6)
Vane or dummy rod and vane shaft - A
TE
This drawing shows position of vane in auger hole.
For use with drive pipe, top assembly disconnected at base plate flange and coupled to drive pipe.
3. For details see attached drawings A - F As indicated each item.
4 For carrying case details see Figure .
ELEVATION

FIGURE 5

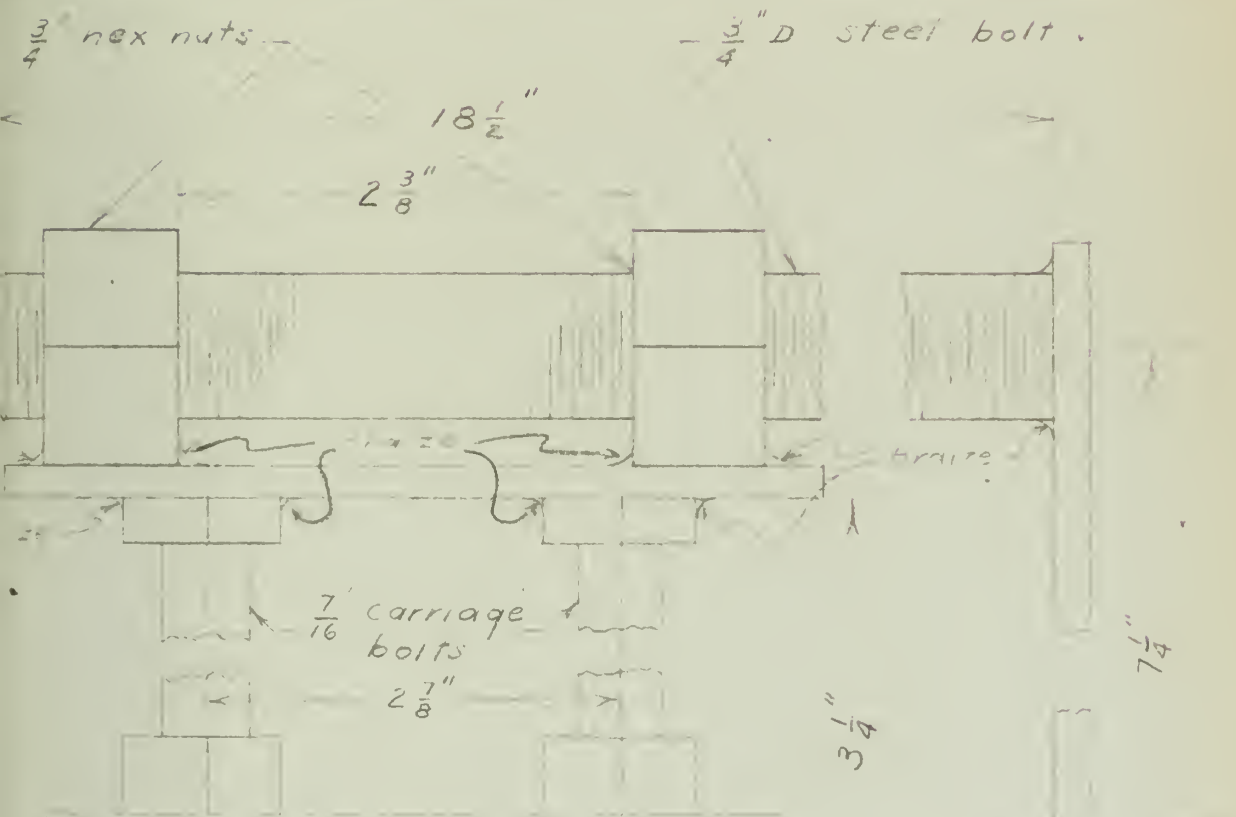


VANE AND VANE SHAFT

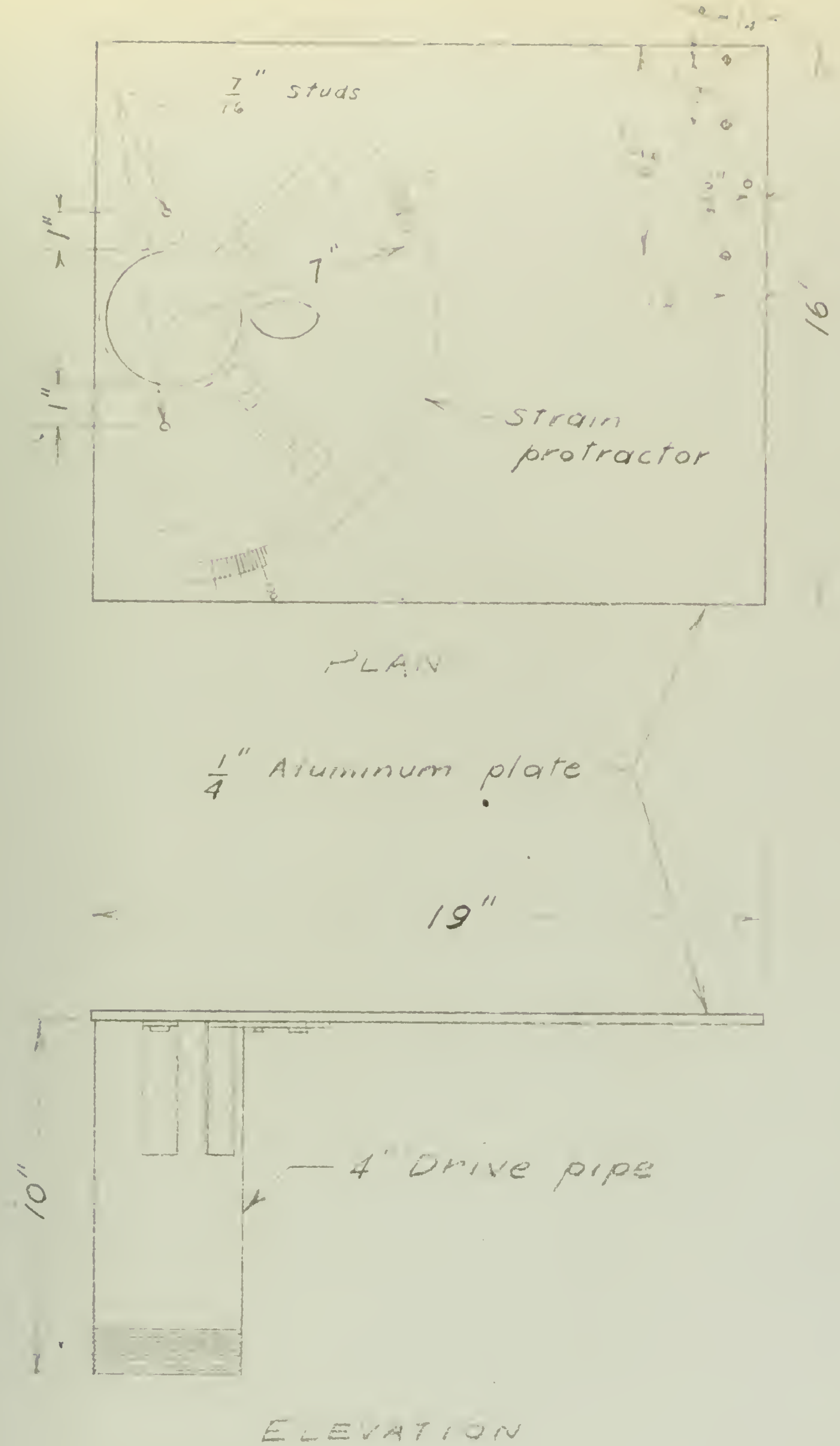
(A)



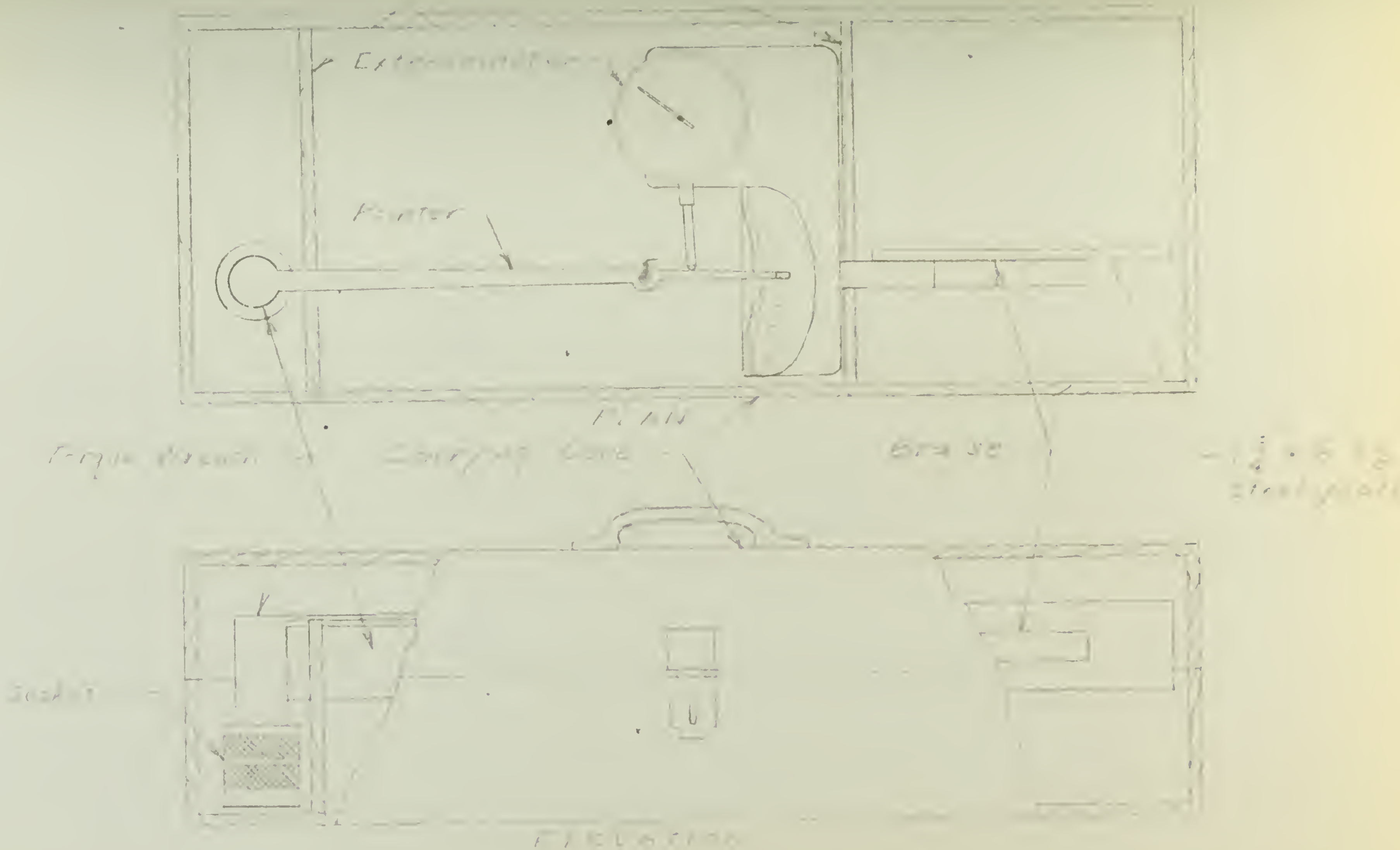
AIR HOSE QUICK COUPLING (B)



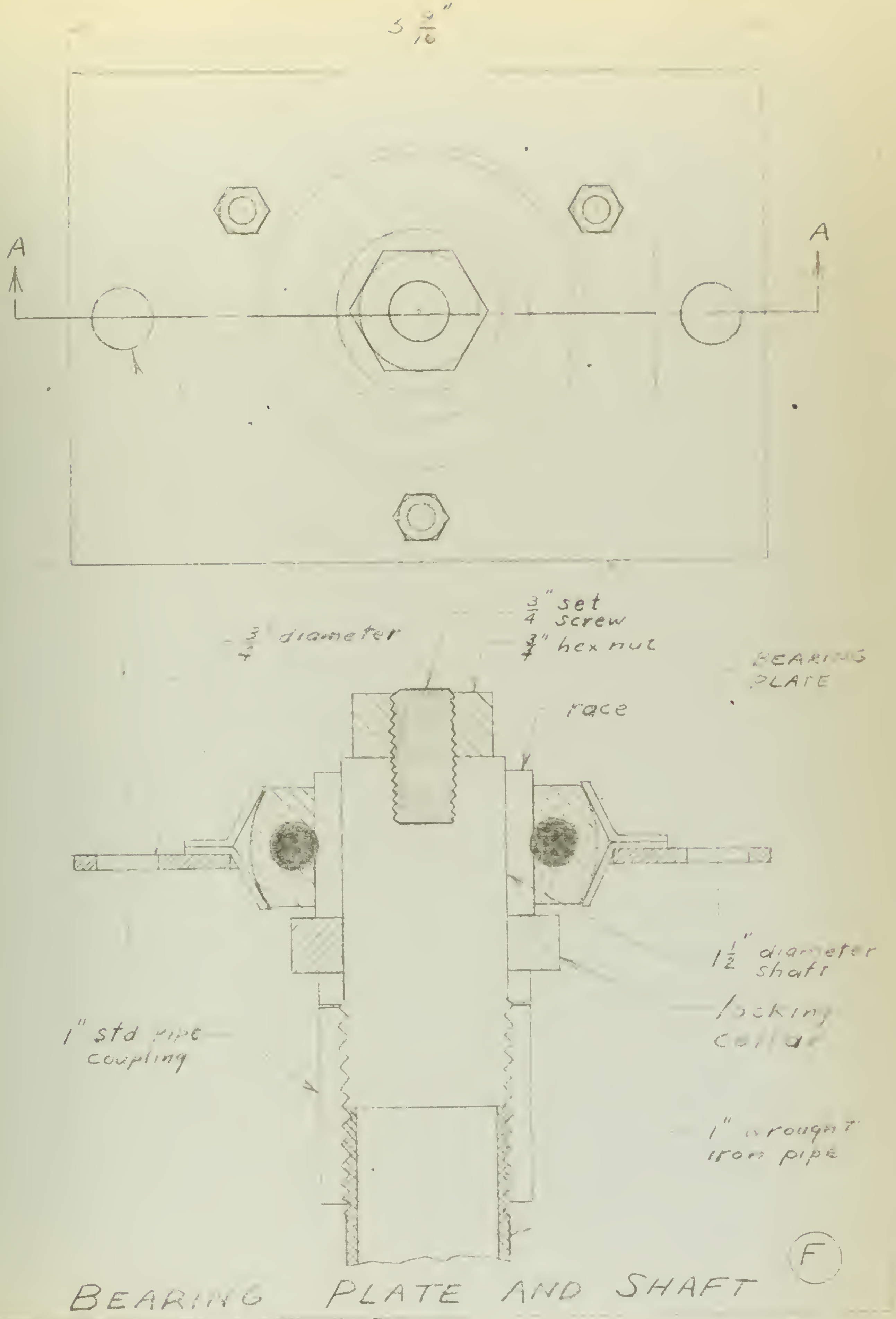
READY BOLT (C)



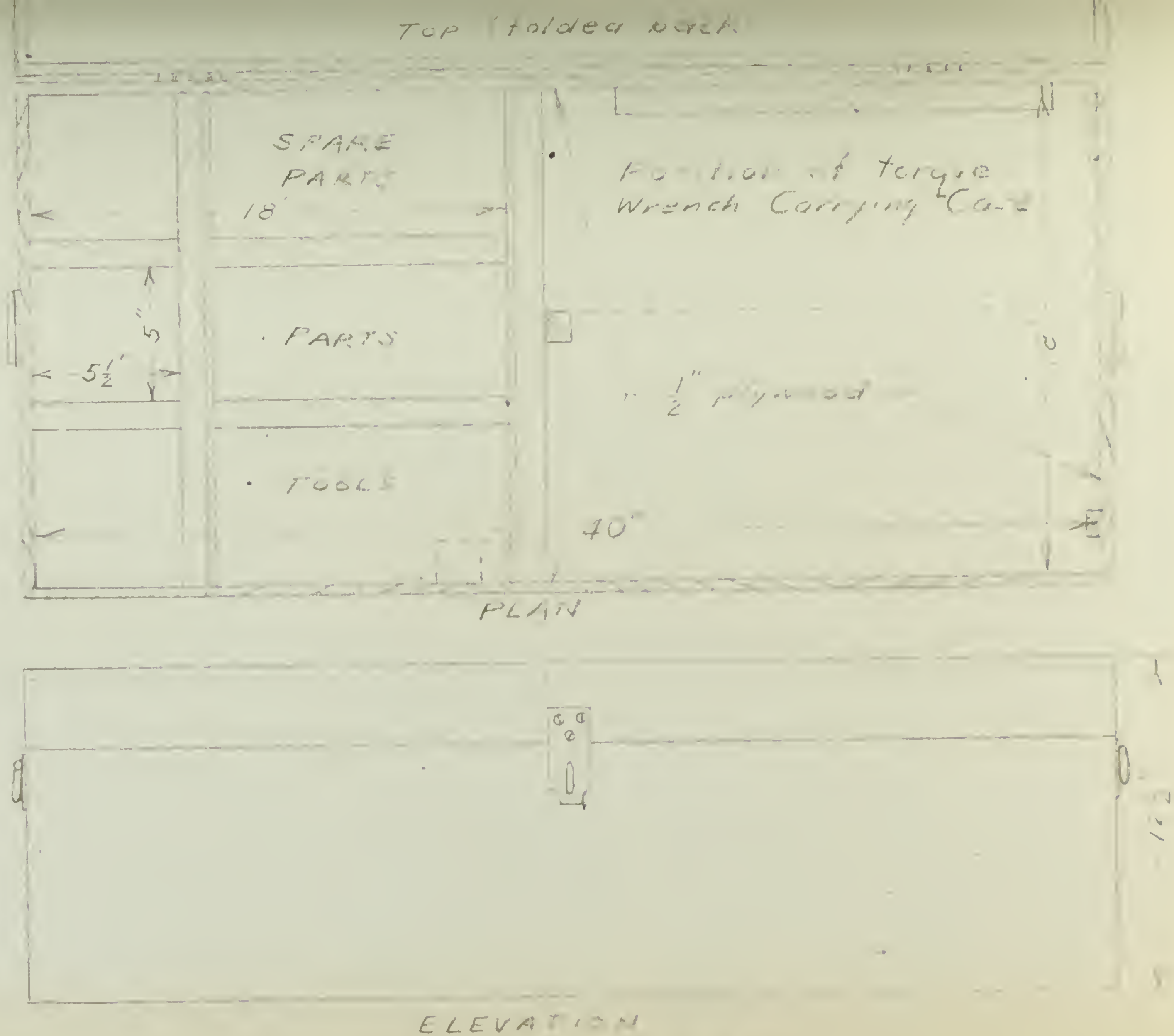
STRAIN PLATE D



TORQUE WRENCH AND CARRYING CASE (E)



BEARING PLATE AND SHAFT



CARRYING CASE

FIGURE 6

BILL OF MATERIALS

Quantity	Unit	Size	Item
4	sq. ft.	1/8 "	Steel plate, cold-rolled
16	inches	$1\frac{1}{2}$" diameter	Steel bar stock
48	ft.	1"	Aluminum pipe (61ST-6)
18	ea.	1"	Air hose quick couplings, bronze, female.
1	ft.	1"	Pipe, wrought iron
8	ea.	1"	Couplings, standard
1	ea.	1 5/16"	Bearing, ball, similar or equal to Fafnir Flangette.
1	ea.	3/4" X 1 3/4"	Set screw
1	ea.	3/4"	Hex units, semi-finished
1	ea.		Socket, similar or equal to B & S 5-1240
1	ea.	0-100 ft. lbs.	Torque Wrench, similar or equal to Bonney 0-100
1	ea.	3/4"	Ready-bolt, 10 threads per inch.
2	ea.	3/4"	Hex units, C.P.
10	ft.	3/16"	Cable, aircraft
1	ea.	4" X 10"	Pipe, drive, steel
6	ea.	5/8" X $1\frac{1}{2}$"	Bolts, hex head
2	ea.	1/8"	Clamps, cable
1	pc.	3' X 3' X 3/4"	Plywood
1	ea.	4"	Flange, pipe

TABLE - 2

BILL OF MATERIALS (con't)

Quantity	Unit	Size	Item
13	ft.	$\frac{1}{2}$" diameter	Rod, steel
4	ea.	$\frac{1}{2}$"	Pipe straps
9	sq.ft.	1/4"	Plywood
20	sq.ft.	$\frac{1}{2}$"	Plywood
1	ea.	large	Hasp
1	ea.	large	Hinges
1	ea.	small	Hinges
1	ea.	small	Hasp
1	ea.		Handle, screen door type
2	ea.		Handles, trunk
1	qt.		Paint, grey

LIST OF COMPONENT PARTS AND TOOLS

Quantity	Unit	Size	Item
2	ea.	3"D	Vane and vane shaft
1	ea.	4"D	Vane and vane shaft
1	ea.	$1\frac{1}{2}$"D	Dummy rod and shaft
4	lengths	6'	Aluminum pipe, 1", with coupling each end
1	length	3'	Aluminum pipe, 1", with coupling each end
1	length	2'	Aluminum pipe, 1" with coupling each end
1	length	1'	Aluminum pipe, 1", with coupling each end
1	length	6"	Aluminum pipe, 1" with coupling each end
1	ea.		Bearing plate and shaft
1	ea.		Strain plate and pipe stand
1	ea.	0-100 ft.lbs.	Torque wrench with extensometer and socket (all in plywood carrying case)
1	ea.	3'X3'X3/4"	Base Plate with four $\frac{1}{2}$" round anchor rods
1	ea.	4"	Coupling, standard (for use with casing)
1	ea.		Ready bolt assembly
1	ea.	12"X18"X40"	Carrying case, plywood
1	ea.		Sling, cable
1	ea.		Oil can
1	ea.		Jack, car bumper
1	ea.	6"	Auger,soil,with pipe extensions
1	ea.	4"	Pipe wrench

Miscellaneous tools such as crow bar, long-handled shovel, pliers, screwdriver, crescent wrench, socket wrench, hammer, and folding rule.

TABLE -2

(d) The amount of torsional moment (stress) producing a certain strain is measured by the torque wrench extensometer dial as its plunger is pressed in by the torque wrench pointer. This measurement commences as soon as a torque is applied with the vane in a stationary position, and continues as the vane moves until the shearing process is complete.

(e) As the pipe shaft twists, and as the vane rotates in the soil, the amount of strain is measured by the movement of the strain needle (attached to the pointer) with relation to the strain plate protractor scale.

(f) To provide the required force to the torque wrench, and consequent torsional moment to the vane, the ready-bolt is turned by means of its crank at a constant rate of one turn every four seconds until the shearing process is complete. Two positions of the ready-bolt bracket are made in

the strain plate in order to accomodate the torque wrench in various starting positions. These positions are governed by the initial positions of the shaft when the vane is thrust into the soil.

(D) CONCLUSIONS

In general the mechanical operation of the vane testing equipment, as designed, proved satisfactory with minor exceptions. Certain recommendations for improvement in design as a result of these minor defects and in the interest of increased efficiency are provided as follows:

(1) The amount of coupling and uncoupling required in the field was considerably less than that contemplated in the design phase. Little trouble was encountered in lowering and raising sections up to fifteen feet in length in one operation. Because of the nature of the quick couplings, there was some tendency for the pipe shaft to buckle at the joints while pushing the vane into undisturbed soil and during tests.

This tendency was lessened when using the vane in a 4" drive-pipe casing because of the centering guides placed on certain sections of the shaft. However, it is believed that in uncased holes, this buckling permitted the pipe shaft and centering guides to scrape along the hole during the test. This is not as serious as it may sound since dummy rod tests are subject to this same action, and therefore such friction losses would be reflected in the tare reading. Nevertheless, it is considered desirable to have as little buckling as possible, and it is therefore recommended that standard pipe couplings be used in lieu of certain quick couplings. In the original design, all couplings were of the air hose quick coupling type. It is believed that better operation would result if two of the four 6' lengths each be equipped with a standard coupling on one end and a quick coupling on the other, and the remaining two 6' lengths have standard couplings only. In addition to the 3', 2', 1', and 6" lengths now provided with quick couplings, duplicates of each of these lengths should be made up with a quick coupling on one

end and a standard coupling on the other. The bearing, vane, and dummy shafts should retain quick couplings. These revisions can be accomplished with the equipment used in this thesis, i.e. obtaining the 3', 2', 1' and 6" lengths from the spare 6' and 3' lengths and the quick couplings from those replaced by standard couplings. When working in the field, quick couplings should be used wherever numerous connections and disconnections are expected. Standard couplings should be used whenever lengths are added which are expected to remain coupled during that test or series of tests.

(2) Occasionally during testing it was necessary to continue movement of the torque wrench by hand (without the aid of the ready-bolt) when the limit of the ready-bolt travel had been reached. Usually this difficulty occurred when the initial torque wrench position did not match too well either of the two possible positions of the ready-bolt bracket. In order to overcome this problem it is suggested that the design of the strain plate provide for additional ready-bolt positions, continuation of the protractor scale, and

enlargement of the strain plate itself.

(3) The diameter of the vane shaft was, for the sake of simplicity, chosen to be the same as the pipe shaft. It is believed that this relatively large size (1.315") causes unnecessarily high tare values and increased resistance to penetration when thrusting the vane into undisturbed soil by hand or jack. Although the writers feel that this vane shaft size has little effect on the disturbance of the soil at the depth of the vane, particularly with the vane shaft being tapered at the junction of shaft and vane, the force required to jack this large shaft into the soil may well cause more disturbance than if a smaller shaft were used. In view of the above, the use of a smaller diameter ($\frac{1}{2}$") high tensile steel vane shaft, in lieu of the shaft as designed herein, is suggested.

(4) The 3" vane is recommended for use in soils, the shear strength of which is expected to vary considerably with depth, and when operating in a drive pipe casing. With this vane relatively accurate measurements of shear strength from 0 to 1000 lbs./sq.ft. (considering tare deductions) are possible.

The 4" vane is recommended for soils known to have a shear strength less than 450 lbs./sq.ft. It will provide a higher degree of sensitivity than the 3" vane in the 0 to 450 lbs./sq.ft. range. Although not used in this thesis, a 2"wide X 4" high vane is recommended for use in soils for the shear strength range 1000 - 3300 lbs./sq.ft. Because of the lesser force required to turn this vane in soil as compared with the 3" size (varies inversely as the cube of the 2" and 3" dimension) it may be used in soils of higher shear strength without exceeding the capacity of the torque wrench and dial.

FABRICATION

The fabrication and design phases of the work went hand in hand. As fabrication difficulties were encountered, changes in design were made accordingly. Therefore, since the writers were obliged to manufacture (or have manufactured) and/or procure and assemble all parts of the equipment, as well as operate the finished device, it is believed that a workable design has been evolved.

Some difficulty was experienced in the procurement of parts. An attempt was made in the design to specify standard items wherever possible since the use of non-standard items usually necessitated special fabrication methods. However, even though most of the parts used were standard, many were utilized for purposes other than that for which they were designed by commercial manufacturers. For example, the aluminum pipe was used as a shaft to transmit torsional moment rather than as a conduit subjected to internal pressure. The air hose quick couplings are another similar example.

As mentioned in the Design phase a suitable pulley to be used as a torque wheel was not available locally primarily because of the large size (20" diameter) desired. All pulleys investigated in this size were

found to be too heavy to use. As also presented in the Design phase, a sensitive spring balance possessing the required range could not be found locally. If a hand winch had been used as the apparatus to produce the torsional moment, it would have been necessary because of its small size to "custom-build" it. Therefore, the torque wrench arrangement was chosen instead of the wheel.

The question of whether to braise or weld arose. Since welding produces a high heat which would cause buckling and warping, and since braising affords a strong enough connection, the latter method was employed.

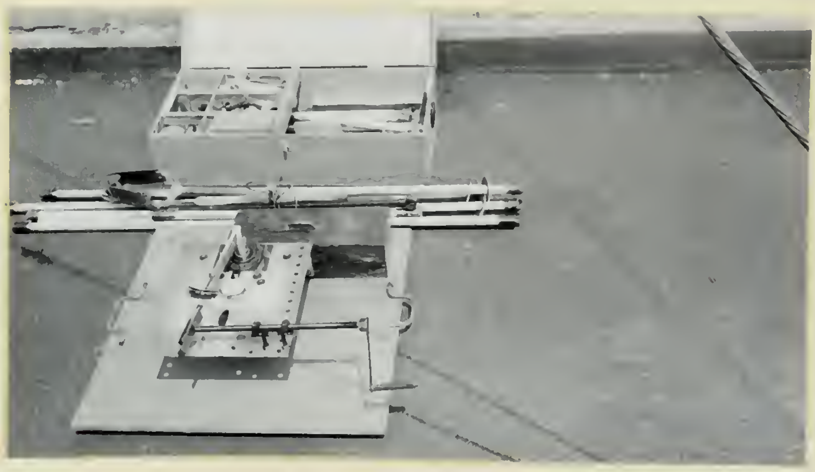
Several torque wrenches considered were rejected even though they had the capacity, because there was no practical way in which to modify them to yield the required degree of accuracy in reading the scale. This was particularly true of those with enclosed dials. The torque wrench finally selected is similar to those normally used in automobile repair shops or other industrial organizations. It was a relatively simple matter to adapt this wrench to the writers' needs.

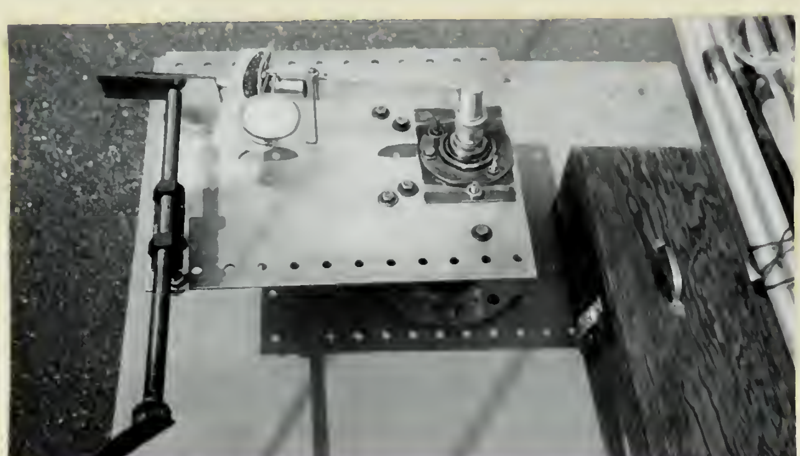
Most portions of this vane equipment can be fabricated by semi-skilled or unskilled personnel. Certain parts such as the piece connecting the vane

shaft and vane should be cut by a machinist. Metal burning and braising should be done by experienced personnel. The carpentry work, pipe-cutting and threading, strain plate fabrication, and certain assembly work can be done by other than skilled workers.

It is realized that the items mentioned above may seem to be of minor importance. However, it is hoped that a brief discussion of some of the fabrication problems encountered by the writers may be of some assistance to others desiring to manufacture, or have manufactured, similar equipment.

Photographs of the writers' completely fabricated vane testing equipment along with necessary accessories are shown by Figure 7.





Completely Fabricated Equipment

FIGURE - 7

PREPARATION AND USE OF EQUIPMENT

(A) TORQUE WRENCH CALIBRATION

Because the divisions on the scale provided on the torque wrench permitted relatively rough readings only, an extensometer was attached to it. As stated under "Design", this instrument permits readings to the nearest 1.2 inch pounds, whereas the torque wrench scale is graduated to be read to the nearest 60 inch pounds.

In order to enable conversion of extensometer dial readings to inch pounds, (and further to pounds per square foot), it was necessary to calibrate the extensometer dial. This calibration was accomplished by means of a torque measuring machine. The wrench was placed in this machine and subjected to various torques, increasing from zero to the upper limit of the dial (1000 units) in increments of 20 units. For each dial reading a corresponding torque machine meter reading in inch pounds was recorded.

Several trials were made to provide a verification of the first calibration. Discrepancies occurred in the lower ranges (0-200 inch pounds). In order to obtain accurate values for this range, a procedure was employed utilizing various weights suspended from the

free (handle) end of the torque wrench, the opposite end of which was held rigidly in a vise.

From the results of the tests described above, calibration curves were plotted with inch pounds as the ordinates and dial readings as the abscissas. These curves, which are plotted for 200 dial units per sheet to give a larger scale, are presented herein by Figure 8.

(B) FIELD PROCEDURE

The writers designed the vane equipment with the thought that it could in its entirety be transported by station wagon (or automobile if necessary), easily carried to and from the vehicle to the site and operated by two men. The weight of the loaded carrying case is approximately 250 pounds. The base plate weighs about 35 pounds and the pipe lengths carried in the sling along with hand tools (auger, shovel, crow-bar, etc.) weigh about 50 pounds. In the field tests made by the writers, all gear was transported in an automobile, carried to and from test sites and operated by them.

A description of the normal use of this equipment with auger holes, follows. When the test site has been selected, a hole is dug to a depth of 30" less

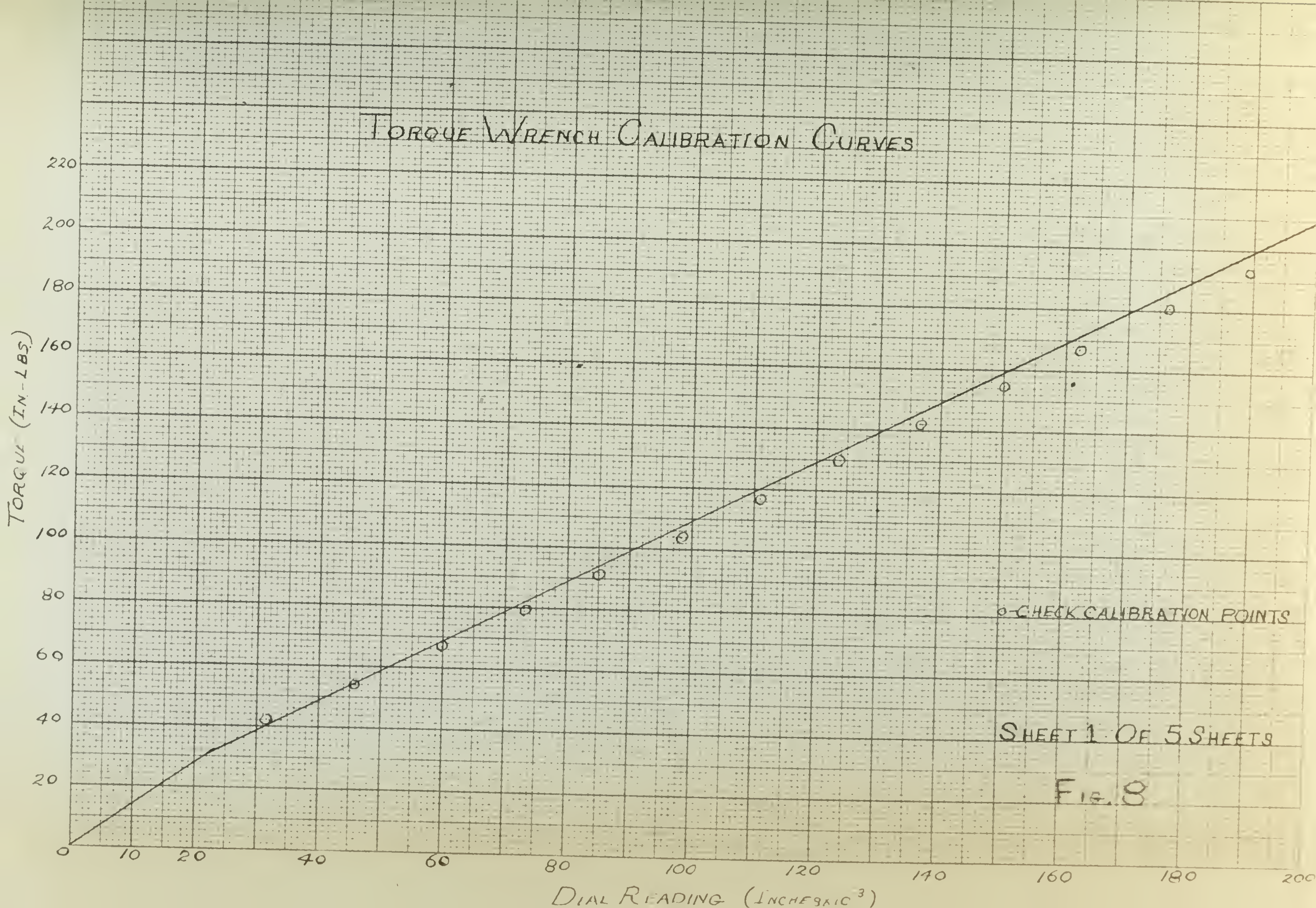
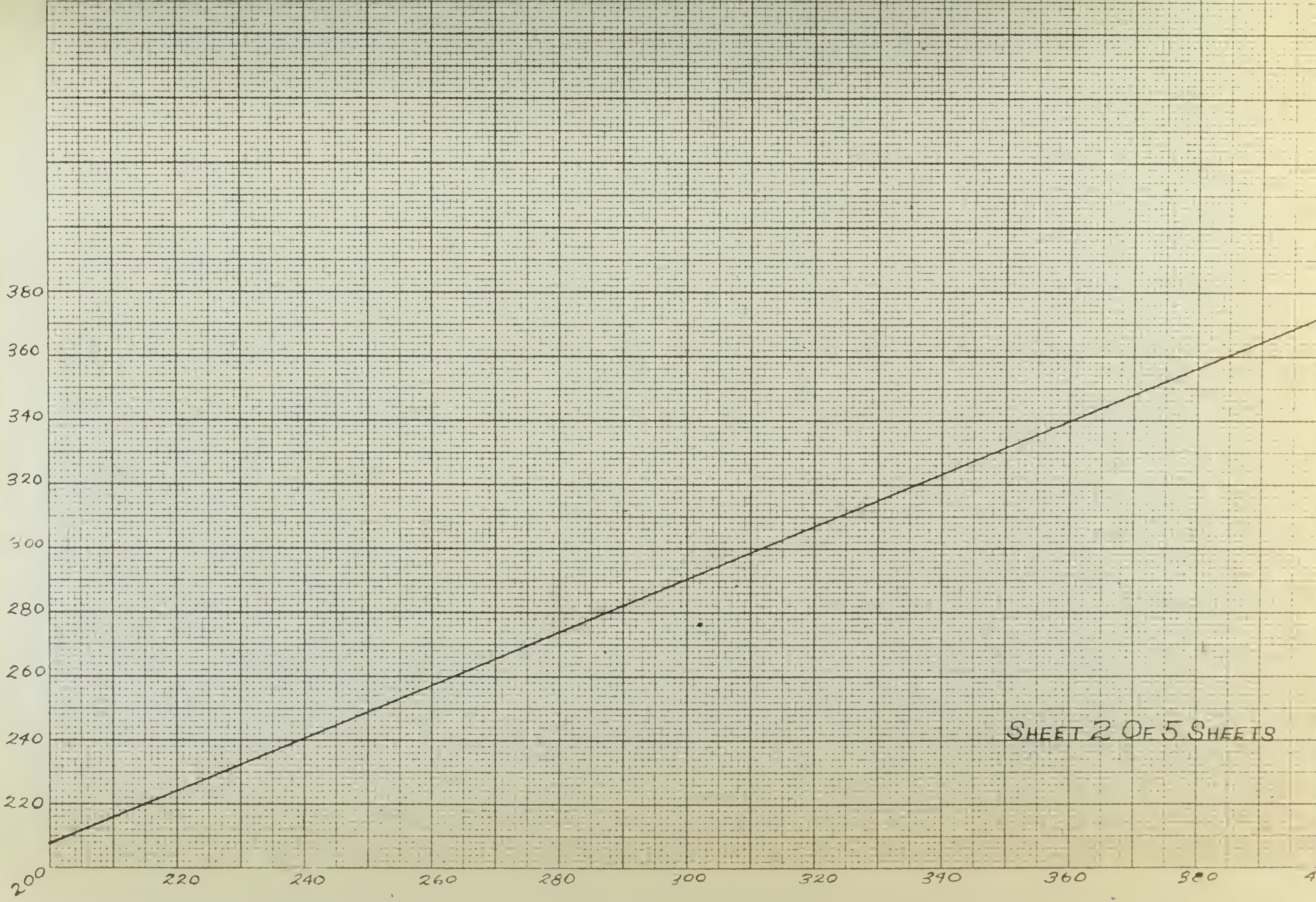
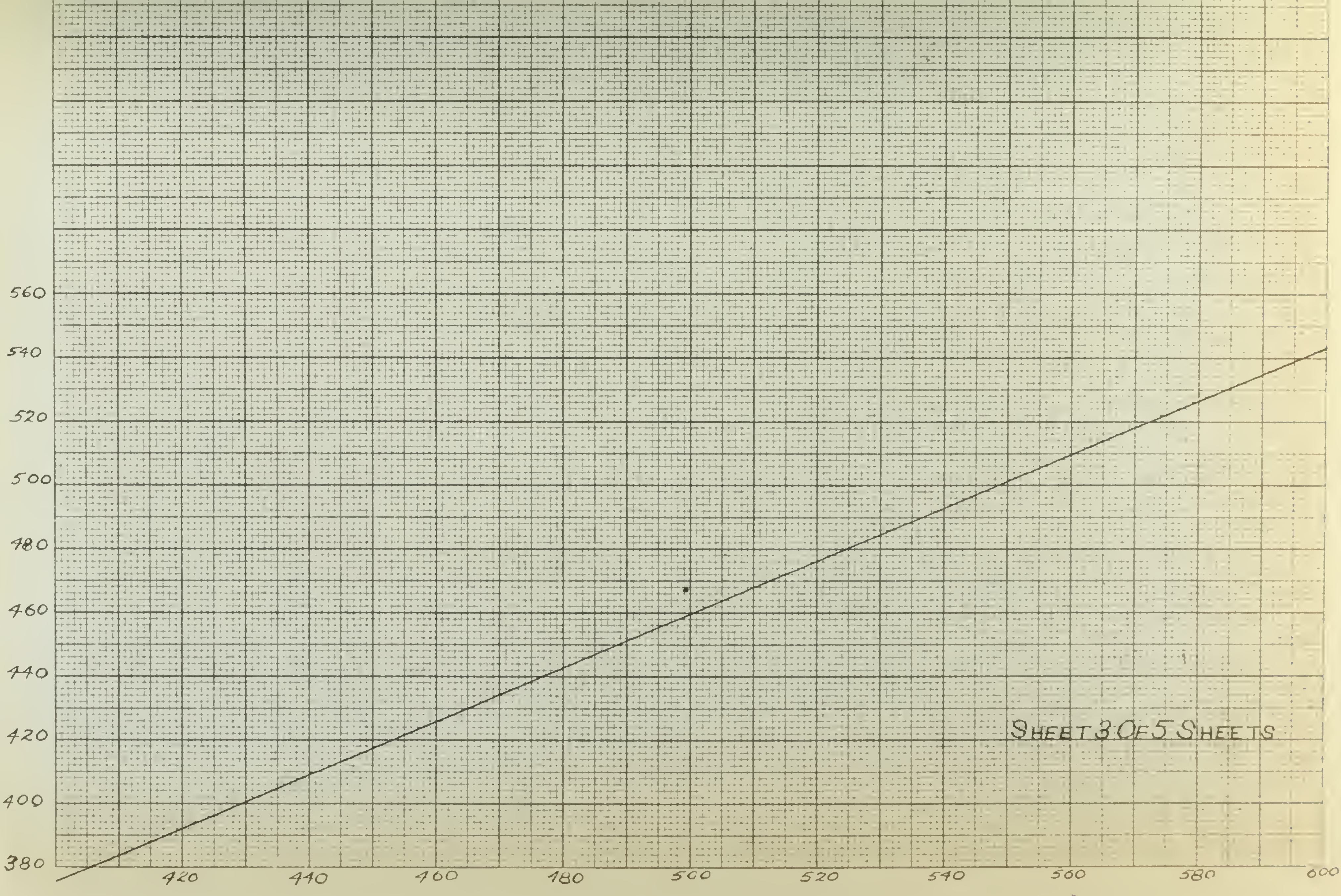
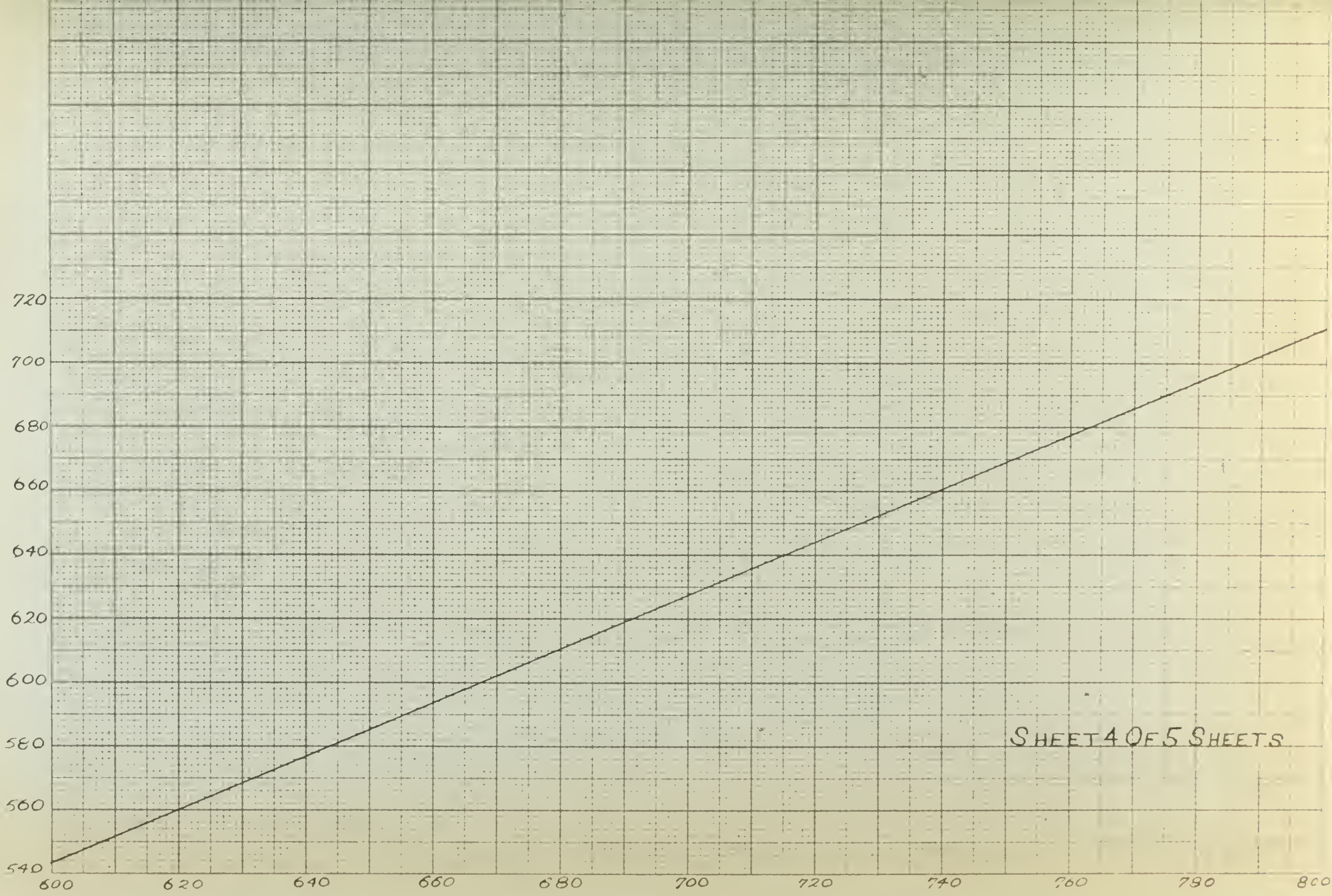

TORQUE WRENCH CALIBRATION CURVES
TORQUE (IN-LBS)
DIAL READING
0
10
20
40
60
80
100
120
140
160
180
200
220
o-CHECK CALIBRATION POINTS
SHEET 1 OF 5 SHEETS

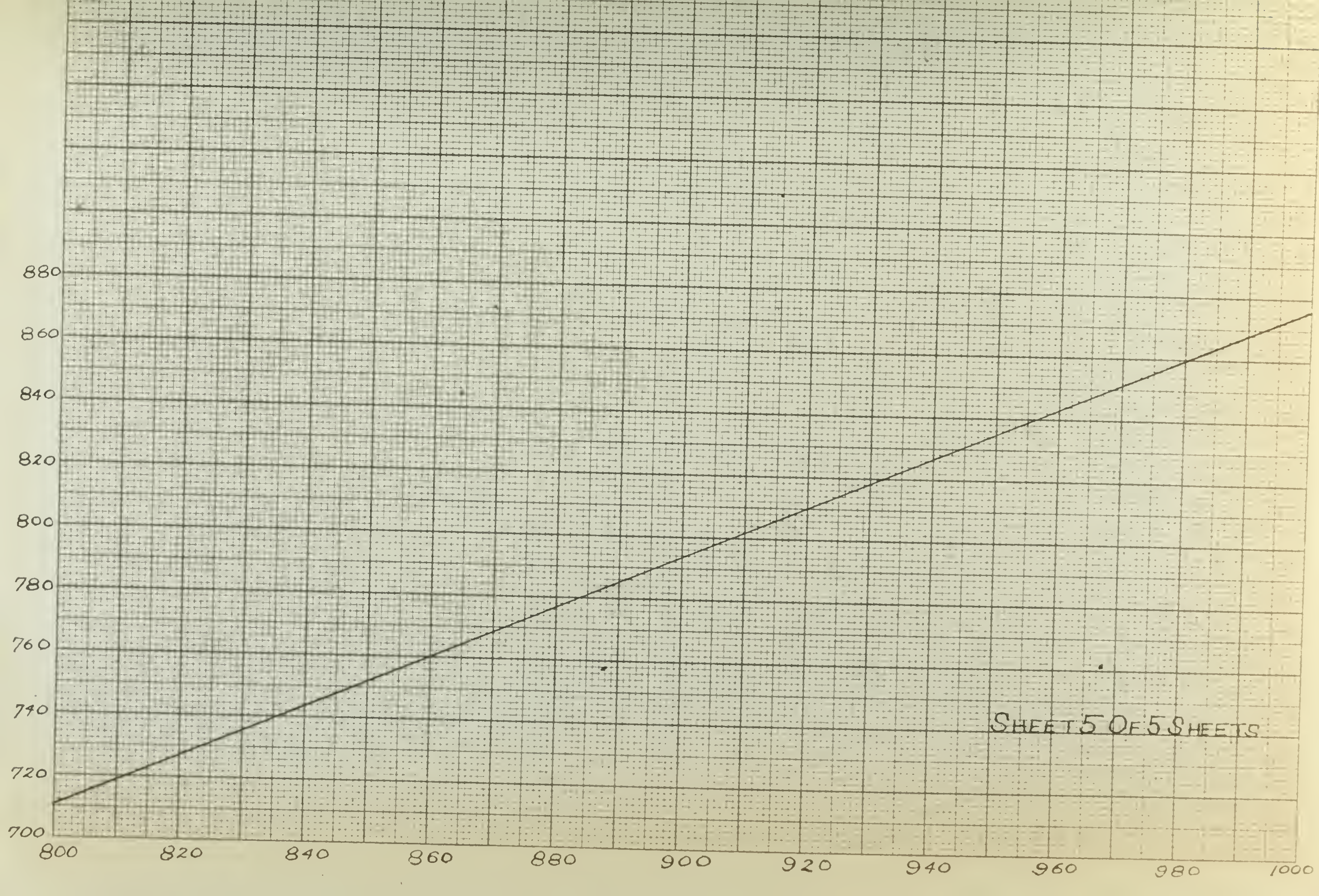
FIG. 8


380
360
340
320
300
280
260
240
220
200
220
240
260
280
300
320
340
360
380
400
Sheet 2 Of 5 Sheets



560
540
520
500
480
460
440
420
400
380
420
440
460
480
500
520
540
560
580
600
SHEET 3 OF 5 SHEETS


720
700
680
660
640
620
600
580
560
540
600
620
640
660
680
700
720
740
760
780
800
SHEET 4 OF 5 SHEETS


880
860
840
820
800
780
760
740
720
700
800
820
840
860
880
900
920
940
960
980
1000
SHEET 5 OF 5 SHEETS

than the depth at which the soil shear strength is desired. The base plate is then centered over the hole and anchors inserted and driven. With a vertical hole it is necessary to level the base plate by the use of dunnage and shims. Next, the strain plate and stand (4" drive pipe) is mounted on the base plate by coupling the stand and base-plate flange. With a 3" or smaller vane, the vane shaft is connected to the required length or lengths by joining at quick couplings, and is then lowered through the pipe stand into the hole. This joining may be done by connecting the lengths one at a time just above the strain plate and lowering the assembly section by section, or, if the full length of shaft is not too great (say 15' or less) then it can be completely coupled in a horizontal position, raised to the vertical position and lowered into the hole.

After the total desired length of shaft is assembled, the bearing plate shaft is connected. The vane is, at that point, resting on the bottom of the hole ready for penetration. In this position the bearing plate is about 30" above the strain plate. The bearing plate is then lowered to the elevation of the strain plate and secured to it by means of threading

nuts on studs attached to the strain plate. In certain soils penetration may be done by the weight of one's body, but ordinarily jacking is required. This may be accomplished with an automobile bumper jack or similar device. A built-in-jack recommended for use instead of a bumper jack is described under part (B) of "Discussion".

It is believed that driving the vane into the soil by sledge hammer or other similar means would be detrimental to test work. The vibrations accompanying such driving would probably cause undue disturbance of the soil in the region adjacent to the vane.

When the bearing plate has been secured, the torque wrench is attached at the top of the pipe shaft. The relative position of the wrench so placed will determine the location of the ready-bolt bracket, which is then mounted on the strain plate. A small socket wrench may be used for both this and the bearing plate connections. To prevent excessive movement of the unsupported end of the strain plate, a wood block is used as a brace between the strain plate and base plate. With the completion of the above steps, the equipment is ready for operation.

One man records the extensometer dial readings corresponding to strain readings. These strain readings are normally taken in increments of two degrees for vane tests, and five or six degrees for dummy rod and remolded tests. When the initial strain reading is established by the torque wrench position, the strain readings may be recorded in advance for a range of about 45 degrees; if this is done then only the extensometer dial readings corresponding to the predetermined strain readings need actually be recorded during a test. Recording is done on a "Vane Test Data" sheet prepared for that purpose. Some typical test results are provided by Table 3. The right hand portion of the Vane Test Data sheet, which is self-explanatory, should be filled in prior to each test. A brief description of the color, texture, etc. of the soil may be entered under "Remarks".

A profile of each hole and plan view of each test site giving the location of holes should be prepared as tests are made. This record is of considerable value in the correlation of test data. It is suggested that this information be recorded in a field note book such as a transit note book. Typical examples are shown by Figures 9 - 11, inclusive.

VANE TEST DATA TEST No. S-20

Strain Field	(Degrees) con-verted	Dial Reading (In. x 10^{-3})
25	0	0
27	2	37
29	4	63
31	6	80
33	8	125
35	10	167
37	12	208
39	14	240
41	16	260
43	18	280
45	20	286
47	22	287
49	24	283
51	26	276
53	28	270
	REMOLDED	
17	0	0
23	6	44
29	12	56
35	18	65
41	24	76
47	30	85
53	36	90

Test Conducted By: MORE
CUSHMAN

Date 26 MARCH 1953

Location:

Station ONANDAGA LAKE OUTLET, NEW YORK THRUWAY

City NORTH OF SYRACUSE

County ONANDAGA

State NEW YORK

Hole No. WBP - 3

Depth 10'

Sample No. 3 - HOLE WBP-4, DEPTH 10'

Vane . . . . . 3"

Max. Dial Reading 288
(Strain At Failure 22 °)

Tare Dial Reading 135
(Dummy Test No. S-19D & S-23D)

Max. Net Dial Reading 153

Max. Torque 163 In-Lbs.

Constant 1.455

Max. Shear 237 Lbs/sq.ft.

Max. Shear From: (Lbs/sq.ft.)

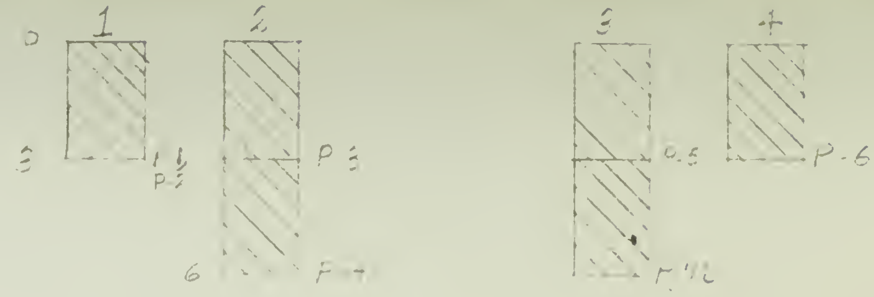
(1) Triaxial Test

(2) Unconfined Compression

(3) Direct Shear

Remarks:
(1.) TYPE OF MATERIAL - MARL
(2.) AVERAGE VALUE BETWEEN DUMMY TESTS S-19D, S-23D USED FOR TARE READING.

TYPICAL FIELD NOTES
TABLE - 3



PROFILES

PLOT PLAN

PRELIMINARY VANE TESTS

BY

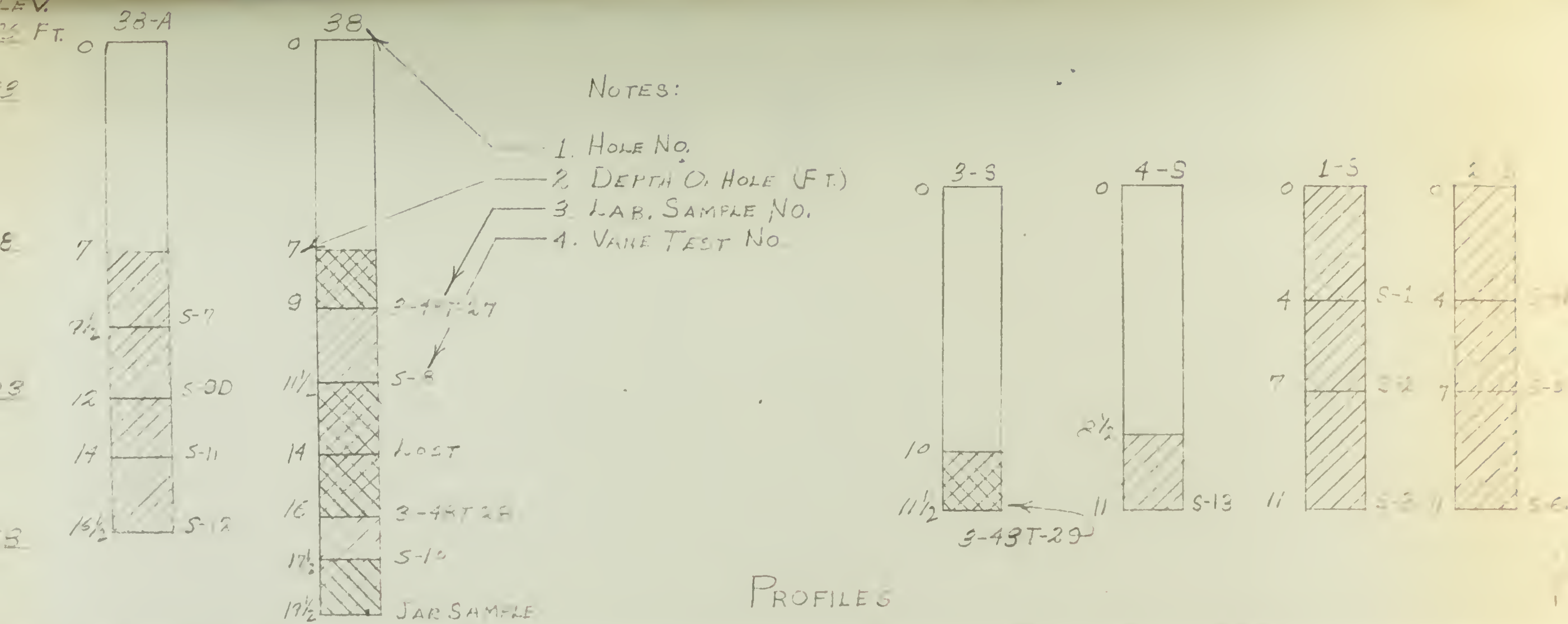
MEEL – SHEERAN

3/12/53, 3/14/53
and
3/17/53

NEW RPI DORMITORY

AREA

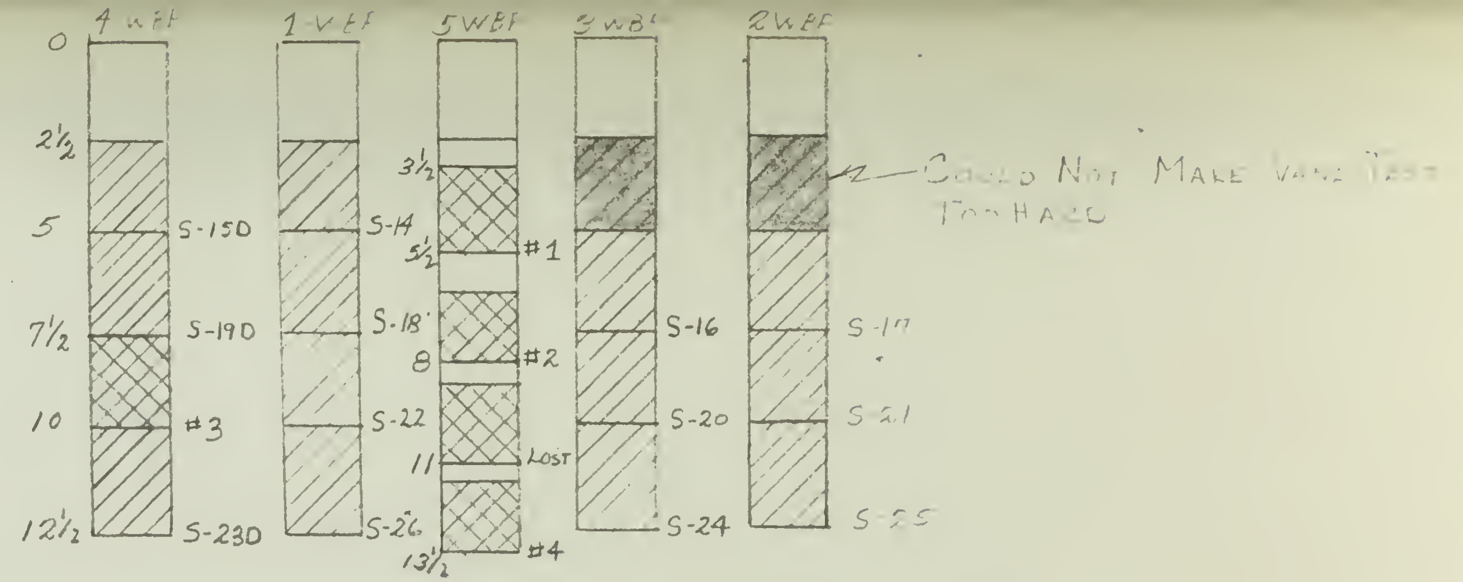
FIG. 9



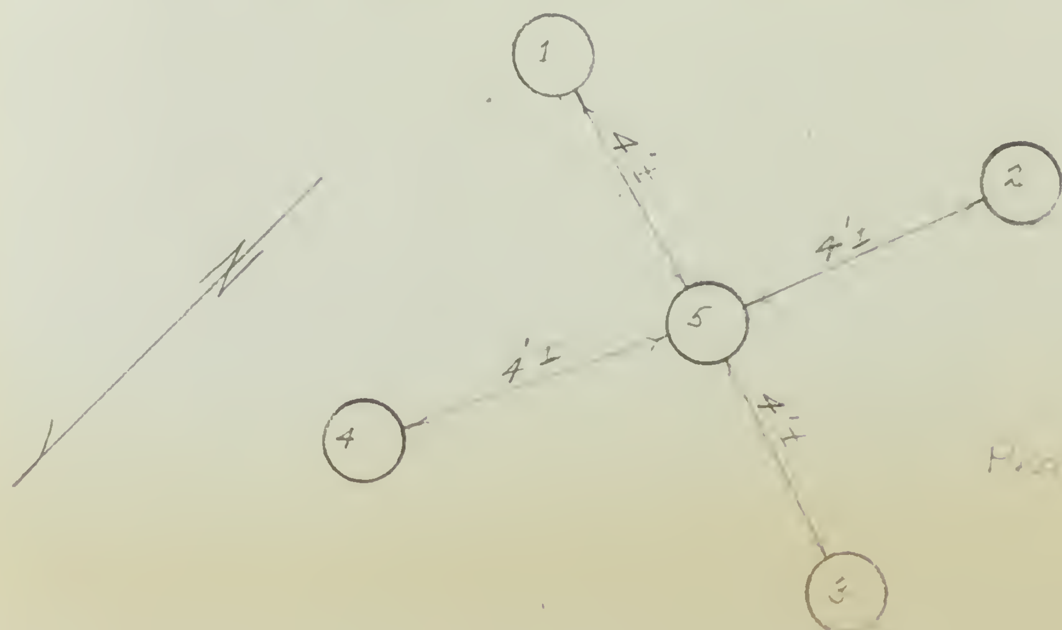
VANE TESTS BY:
MOLE - CUSHMAN
3/24/53 + 3/25/53

OSWEGO BLVD.
ARTERIAL

FIG. 10



Profiles



[illegible] Plan

Vane Tests By

Moir - Cushman
3/26/55

Onondaga Lake Outlet
Crossing of N.Y.S.
Thruway

Fig. 1

The other part of the actual testing operation is that of turning the hand crank at a predetermined rate of one revolution every four seconds. Continuous stop-watch timing may be used at first, but after some practice can be diminished to periodic checking. If the nature of the soil is such, or the original position of the wrench is such, that the ready-bolt travels to its limit, then the man operating the crank must continue the rotation by hand until shear occurs. In doing this he should attempt to turn the torque wrench at approximately the same rate as with the ready-bolt. He must also watch for excessive slippage of the equipment; this is detected by a sudden drop in the torque wrench extensometer dial reading with no change in the rate of load application. This type of drop in reading is usually much more rapid than the gradual drop which occurs during actual shear. Local failures in the soil surrounding the vane may occur before actual shear failure. However, a sudden drop in dial readings due to this latter phonomenon will not ordinarily be as pronounced as that due to slippage. Although slippage will ordinarily simply result in several scattered points on the stress-strain curves, if it occurs near the failure point it may invalidate that entire test.

If a remolded shear strength value is desired, it should be obtained at the completion of the regular vane test. This is done by rotating the vane shaft (in the same direction as the test) five or six times fairly rapidly to cause remolding and then following the above described test procedure. For remolded tests it is usually satisfactory to turn the torque wrench by hand rather than reengage the ready-bolt.

Dummy rod tests should be run at approximately the same depths as regular vane tests if possible. However, with a relatively homogeneous soil, alternating dummy rod tests with vane tests may provide sufficiently accurate tare values. In stratified soils it is prudent to make dummy tests in a hole adjacent to the vane test. The decision of dummy rod test frequency must necessarily depend upon the experience and judgment of the operators. As a word of caution it should be stated that if a dummy test is made, the hole should be excavated to a point below the elevation of the tip of the dummy rod before another vane test is made. In other words, if the vane shaft is placed in the hole made by the penetration of the dummy rod (as opposed to the larger

hole made by the auger), the shear strength recorded will be too low. This is due to the fact that the adhesion of the soil on the vane shaft would be less than if the vane shaft were thrust into undisturbed soil.

Vane tests using the 4" vane are carried out in the same manner as described above except that the vane must be lowered into the hole before the base plate assembly is centered over the hole. It is convenient to lower the 4" vane and all connected pipe lengths into the hole until the vane is resting on the bottom of the excavated portion of the hole, and then place the base plate assembly in position, after which the bearing plate and bearing plate shaft assembly is attached. The vane is then ready for penetration.

To use the equipment in cased holes the strain plate and stand is coupled to the top section of the 4" drive pipe casing instead of to the base plate. Vanes of 3" diameter and less may be used with this size casing. Allowance must be made for height of casing above ground and for bracing the strain plate to prevent its turning on the casing and to keep the casing from turning during tests. Otherwise, operation

with drive pipe casings is no different from that with the base plate.

Referring back to actual test procedure, there are certain steps to be taken at the completion of each field test in order that the shear strength value may be determined. The strain readings for vane, remolded, and dummy rod tests are converted to the common base of zero. Stress-strain curves are then plotted with extensometer dial readings (inches X 10^{-3}) as the ordinates and strain readings (degrees) as the abscissas. The results of several tests may be plotted on the same graph. Some typical stress-strain curves are provided by Figures 13 - 16 inclusive.

The maximum dial reading is obtained from the stess-strain curve plotted from field test data. This is done by determining the point at which a horizontal line is tangent to the highest portion of the curve. The tare dial reading for the same amount of strain is found from the appropriate dummy rod test stess-strain curve in the same manner. Subtracting the tare dial reading from the maximum (gross) dial reading provides the maximum net dial reading value. The torque wrench calibration curve (Figure 8) is then entered , with the latter reading as the abscissa, and the corresponding

torque reading in inch pounds is recorded on the Data sheet. To obtain the maximum shear value in lbs./sq.ft., the maximum torque reading is multiplied by a pre-determined constant (1.455 for the 3" vane) which depends on the diameter of the vane and assumed stress distribution as explained in "Preliminary Investigations".

(C) TESTS

After completion of the fabrication phase of the vane testing equipment, it was intended to make such field tests as time permitted for the purpose of testing its mechanical operation, and if possible, to calibrate it by comparing field test data with laboratory test results. A summary of tests performed is as follows:

Location	No. Vane Tests	(No. Remolded Tests)	No Dummy Tests	Total No. Tests
New R.P.I. dormitory area	5	(4)	2	7
Syracuse-Oswego Blvd.	10	(7)	3	13
Syracuse-Onondaga Lake Outlet	10	(2)	3	13

(1) Preliminary - To permit the writers to become accustomed to operating the equipment under actual

field conditions, and to test mechanical operation of the apparatus, seven tests were conducted in an area just west of Burdett Ave., and just south of the new Rensselaer Polytechnic Institute dormitory construction project area in Troy. Of the total number of tests made, five were vane, and two were dummy rod tests. The predominant material encountered was a relatively stiff, dense, blue clay known as Albany Clay (per Mr. Hofmann, New York State Soil Mechanics Laboratory, Latham, N. Y.). No particular mechanical difficulties were experienced except those encountered in jacking the vane in and out of the soil. When an attempt was made to jack the vane into a dense mixture of sand and clay (just above the blue clay layer) it was found practically impossible to do so. A test made in the transition zone between this fill material and the blue clay indicated that its shear strength was considerably above the 1000 lbs./sq.ft. limit of the 3" vane, since the stress built up rapidly to the maximum dial reading, beyond which point the test could not be continued. This is believed to be a logical explanation of the inability to penetrate this type of soil with the vane using ordinary jacking methods. As a result of this

problem, the bottom edges of the 3" vane blades were ground to a V-shape to facilitate penetration.

A profile and plan view of the area in which the tests were conducted in the Albany Clay is afforded by Figure 9. Typical stress-strain curves for these tests are shown in Figure 13. This figure provides a comparison of the characteristics of vane, remolded and dummy rod test curves. Photographs of certain field operations comprise Figure 12.

(2) Final - It was recognized at the outset by the writers that calibration of the equipment by means of comparison of field results with laboratory tests would ordinarily involve more time than the thesis period allowed if they were to attempt both of these functions, and that they might not be able to even attempt that phase of the work. However, fortunately the opportunity presented itself for the writers to operate the vane equipment in conjunction with sampling and laboratory tests being conducted by the New York State Department of Public Works Soil Mechanics Laboratory at several sites near Syracuse, N.Y. of the new thruway project.

The first site at which tests were made was located in the Oswego Boulevard arterial area. Vane

Operation of Vane Testing Equipment

FIGURE - 12

tests were made alternately with undisturbed samples taken by the State from a 4" drive-pipe casing. Another casing was driven about 4' from the first and dummy rod tests were made in that casing. In addition, several holes were excavated by auger in an area approximately 30 feet away from the casing location and vane and dummy rod tests conducted for the purpose of comparison with results obtained in the casing. Tests in the Oswego Boulevard area were completed in one and one half working days. A profile and plan view of this area is given by Figure 10. A stress-strain curve of vane and remolded tests made at a depth of 10 feet is provided by Figure 14.

On the third and last day of the field trip, tests were made in the Onondaga Lake Outlet area about 8 miles north of Syracuse. Four holes were laid out, one at each corner of a square having an eight foot diagonal, and one hole was located in the center of the square. It was intended to use one of the four outer holes for dummy rod tests (at the same depths as regular vane tests), two for vane tests, and the remaining one for vane and remolded tests. The hole in the center was to be used by the State for continuous sampling by Shelby Tube. The object of the above-

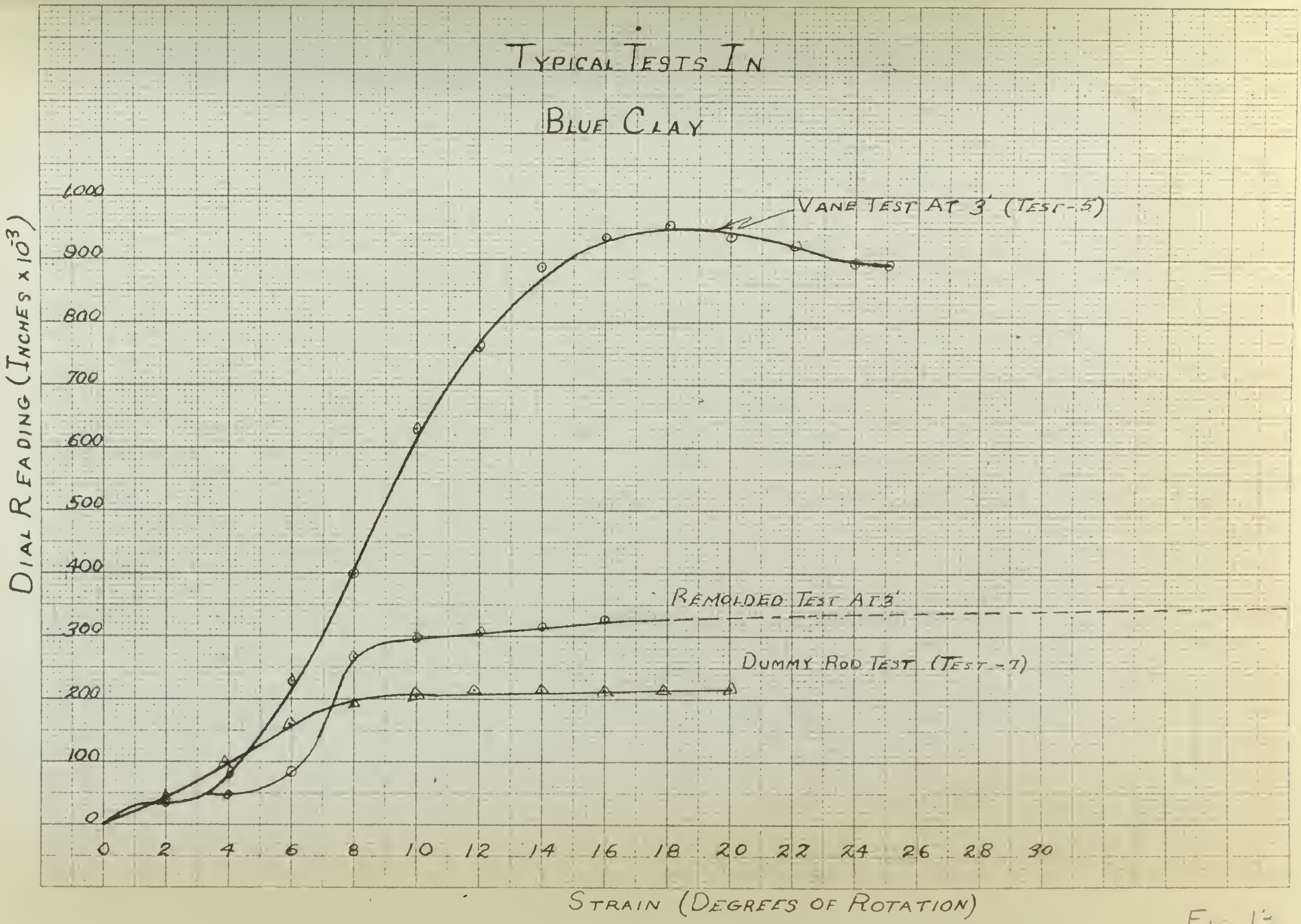
described grouping of holes was to enable the writers to obtain as close correlation as possible between the results of field vane tests and those of laboratory tests made on undisturbed samples taken in adjacent holes at the same depth.

A profile and plan view of the Onondaga Lake Outlet test site is afforded by Figure 11. The results of typical vane and dummy rod tests are plotted as shown in Figures 15 and 16 respectively.

Samples from both the Oswego Boulevard and Onondaga Lake Outlet areas were taken to the New York State Soil Mechanics Laboratory, Latham, N.Y. where shear tests were made on those samples wherein it was possible to do so. In some portions of the samples transported to the laboratory, the structure had been so disturbed that performing shear tests on that portion was impracticable.

It was originally believed that the type of soil in the two Syracuse areas would render vane test results which could easily be correlated with laboratory results. However, the material encountered was a gray, loose, non-homogeneous marl of high calcium (shell) content containing a large percentage of fines and secondary calcium-carbonate-cemented

particles, ranging from gritty to a soft, plastic texture. Accordingly, because the material encountered was so easily disturbed, as indicated by comparison of field and laboratory tests, the object of these field tests was necessarily revised from calibration tests to another phase of the study of vane equipment, namely an investigation of the effects of partial disturbance of soil due to sampling methods, transportation and manipulation. It is considered by the writers, after witnessing the soil sampling and making a visual determination of its physical properties, that there was considerable disturbance of the structure of the marl due to sampling and other necessary handling. This statement is made without any intention of reflection on the care taken in these handling functions, as it is felt that every possible means of preventing disturbance was taken. It is intended to point out, on the other hand, that partial disturbance could not be avoided and that field and laboratory test results should be compared keeping this consideration in mind. This matter is treated in more detail in the "Test Data" portion of the "Discussion" part of this thesis.



Typical Tests In
Blue Clay
Vane Test At 3' (Test-5)
Remolded Test At 3'
Dummy Rod Test (Test-7)
Dial Reading (Inches x 10^{-3})
1000
900
800
700
600
500
400
300
200
100
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Strain (Degrees of Rotation)

Fig. 1

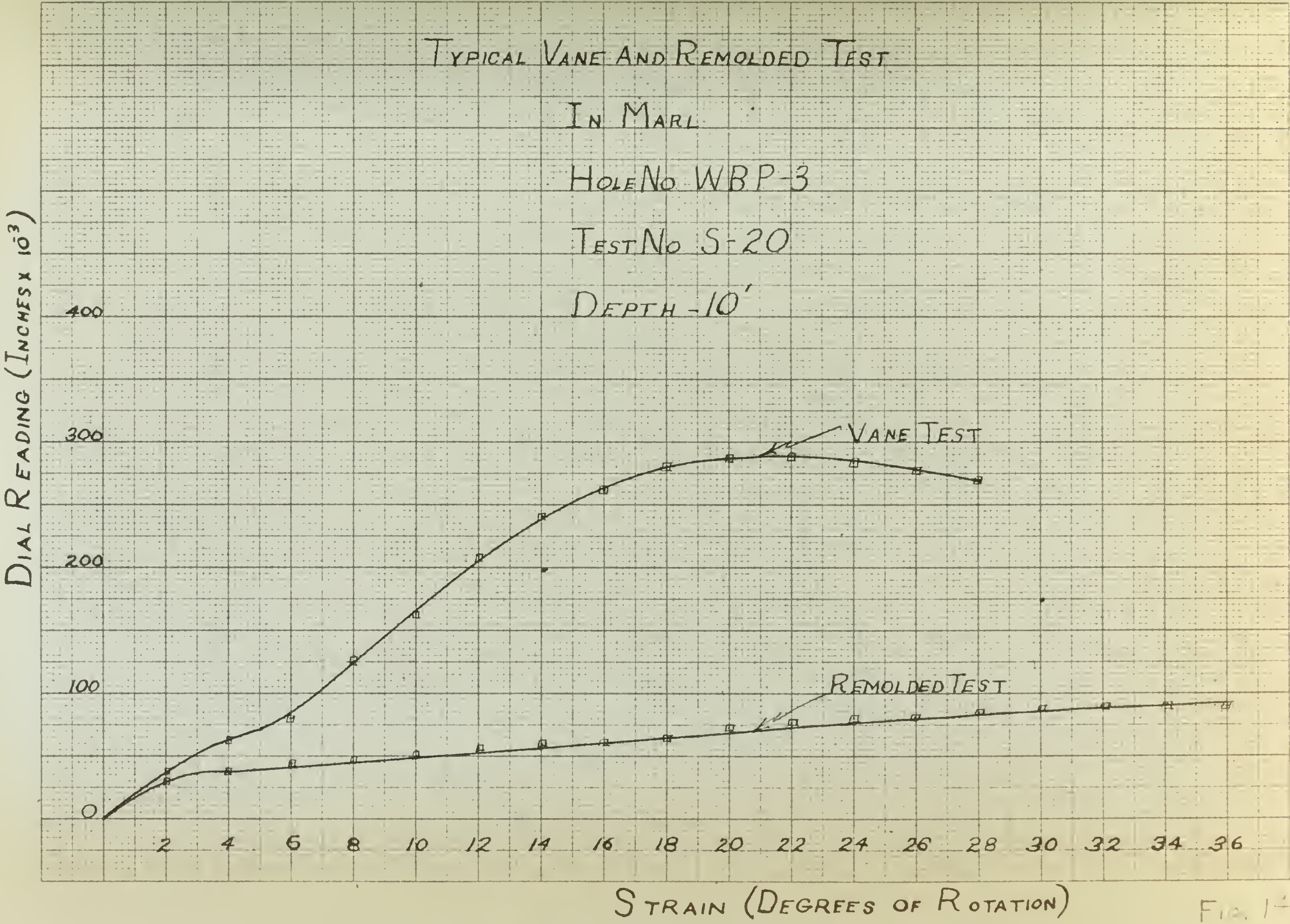
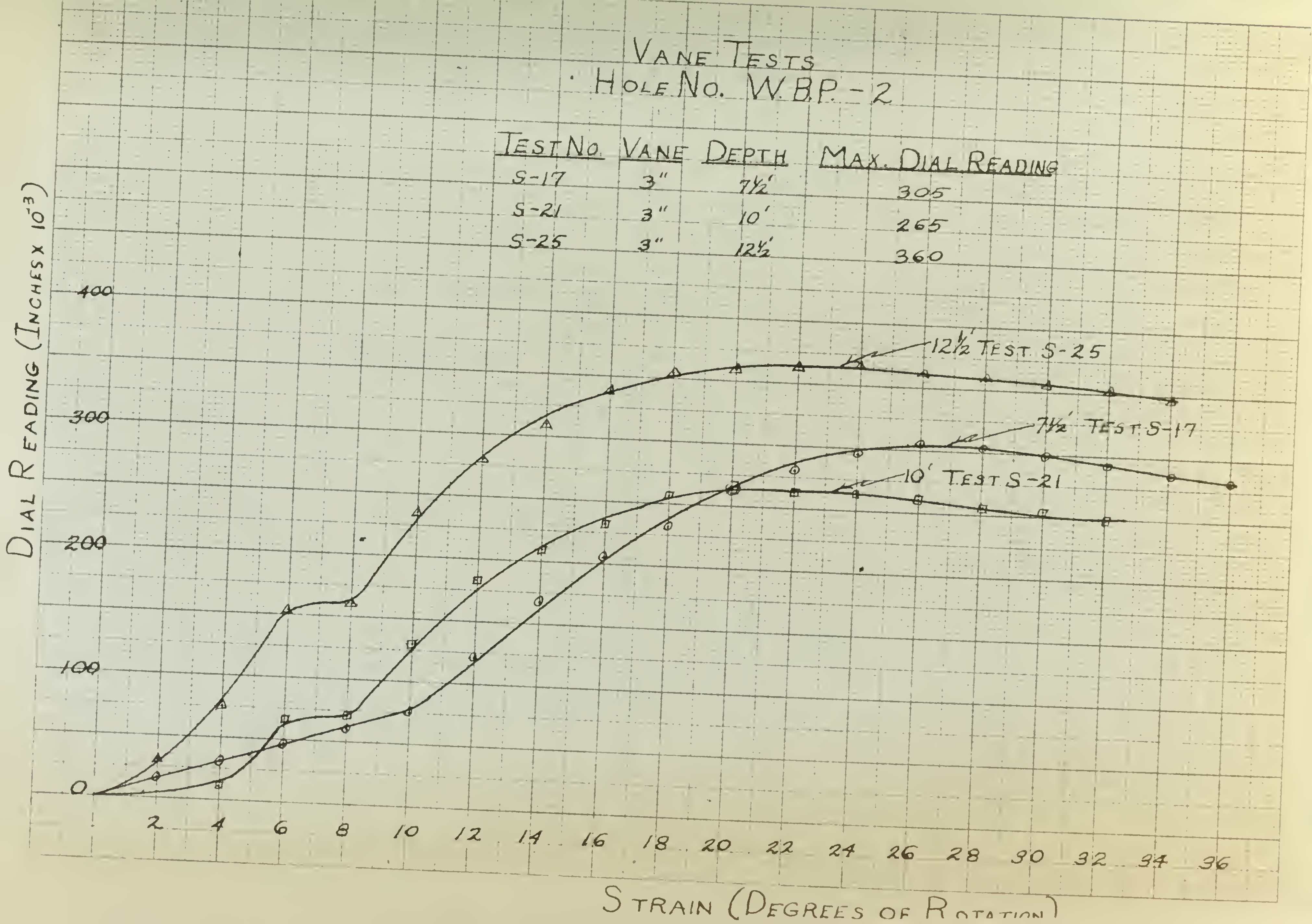
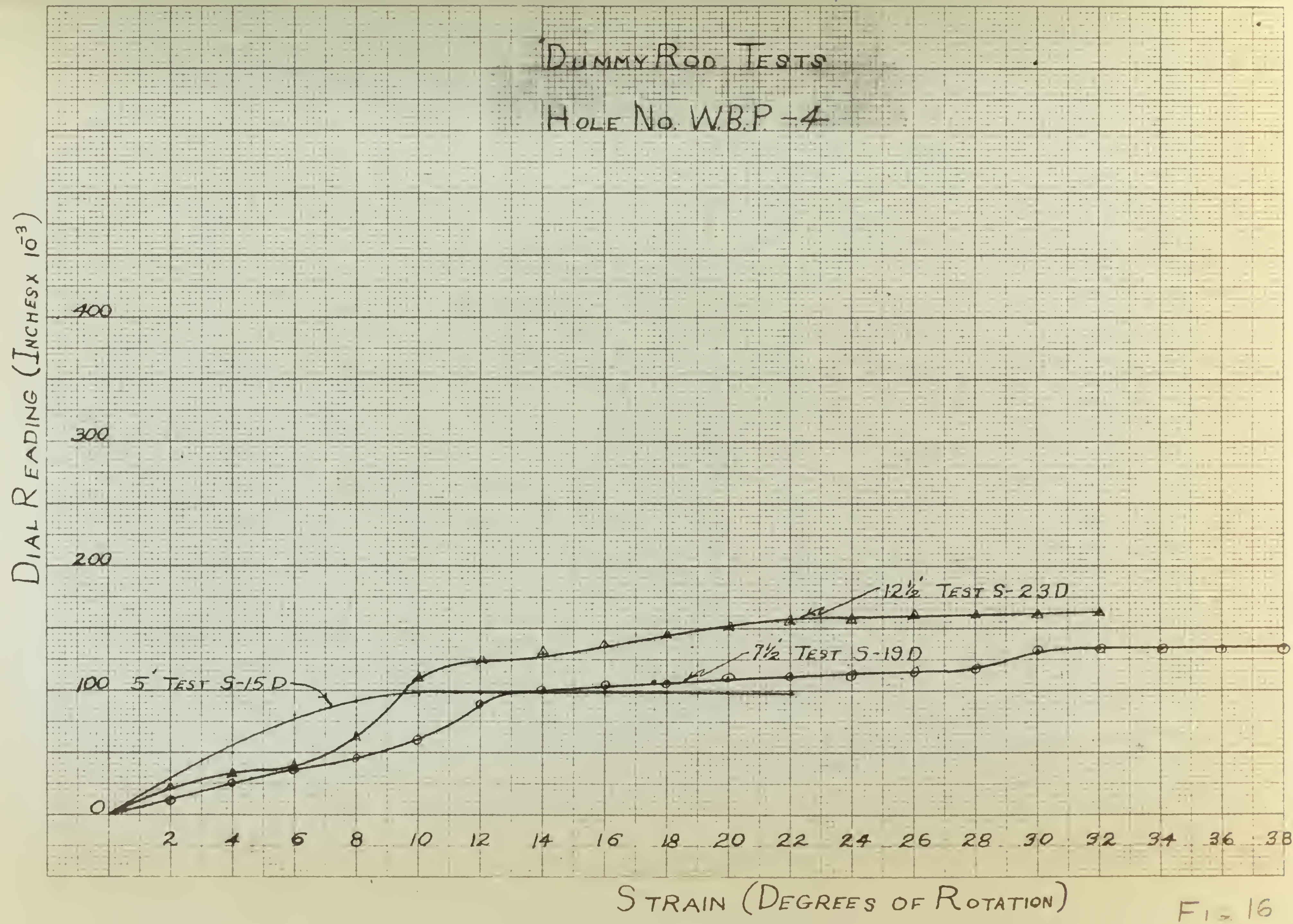

TYPICAL VANE AND REMOLDED TEST
IN MARL
HOLE NO WBP-3
TEST NO S-20
DEPTH -10'
DIAL READING (INCHES x 10^3)
400
300
200
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
VANE TEST
REMOLDED TEST
STRAIN (DEGREES OF ROTATION)

FIG. 1


Vane Tests
Hole No. W.B.P. - 2
Test No. | Vane | Depth | Max. Dial Reading
S-17 | 3" | 7½' | 305
S-21 | 3" | 10' | 265
S-25 | 3" | 12½' | 360
12½' Test S-25
7½' Test S-17
10' Test S-21
Dial Reading (Inches x 10^{-3})
0
100
200
300
400
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36
Strain (Degrees of Rotation)



Dummy Rod Tests
Hole No. W.B.P.-4
Dial Reading (Inches x 10^{-3})
400
300
200
100
0
5' Test S-15 D
7½' Test S-19 D
12½' Test S-23 D
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
Strain (Degrees of Rotation)

Fig. 16

DISCUSSION

(A) TEST DATA

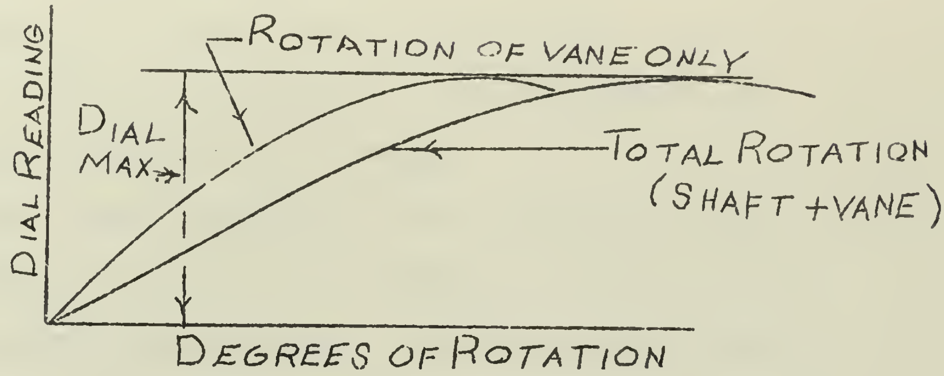
(1) General. All tests were performed for the primary purpose of checking the design and operation of the equipment and, secondly, to use in certain investigations and analysis such tests as time would allow.

As previously stated under "Design", the mechanical operation indicated that the design was of a sound nature. The data obtained from the tests can now be qualitatively analyzed.

(2) Stress Strain Curves. The test data has been plotted with dial readings versus degrees of rotation. The dial reading has a direct relationship with the torsional moment (see "Preparation and Use of Equipment"). This reading then, represents the stress applied. The degrees of rotation represent the strain. Thus the plot is essentially a stress strain curve.

It should be noted, however, that the strain includes the total angle of rotation, i.e. the twist in the shaft and the rotation of the vane. These curves, therefore, do not reflect the instantaneous stress strain relationship in the soil. This information is obtained from the basic data by manipulations similar to those used to develop curves of Figure 4. The maximum dial

reading does directly represent the force on the failure surface. This may be understood more clearly by use of the following sketch.



It is seen that no matter what amount of rotation exists, the energy put into the system reflects itself in exactly the same amount in all cases, that is, the yield (failure) point of all curves for any one particular test, regardless of rotation, is the same. The variation lies in the slope of the curves before the yield point.

The appearance of these stress strain curves yields the definite conclusion that the method chosen to measure the stress and strain is satisfactory. A study of these curves (see Figures 13-16 which are typical curves) reveals the following:

(a) That there is a certain amount of irregularity

in the curves at low strains. This seems to be more pronounced in marl than in the blue clay. The reasons for these irregularities are mainly two fold and are believed to be as follows:

(I) A small slippage in the equipment in adjusting itself to the stress.

(II) Small immediate local failures of the soil adjacent to the vane blades. All tests were run below the water table. As the vane was penetrated into the undisturbed soil, which varied in moisture content, water followed the vane blades and shaft. This water immediately adjacent to the blades changes the characteristics of small portions of the soil allowing local failures to take place immediately after a stress is applied. In addition to the above, a small portion of the soil adjacent to the vane blades is also disturbed further contributing to local shear failures. Because of the water accumulation adjacent to the blades of the vane, every test should be started as soon as possible after penetration. Depending on the type of material, an appreciable delay may affect the results of the test.

(b) That the Albany Clay builds up stress more rapidly than does the marl, that is, the slope of the portion of the stress strain curve preceding the yield point is steeper for the clay. It is the opinion of the writers that the slow increase in stress with increasing strain in the marl is caused by a primary consolidation without appreciable increase in stress.

(c) That the marl fails at a much larger strain than does the Albany clay due to the characteristics mentioned in (b) above.

(d) That the curves for the clay seem to drop off rapidly after the yield point, but in the case of marl descend very gradually. In fact, in the marl the value of stress at the yield point remains the same over a relatively large strain producing a straight line or very flat curve. An explanation of this may be obtained through an analysis of the difference in materials. The clay, for instance, has developed its shear strength mostly through cohesive forces. As soon as the cohesive force is destroyed by the vane, little resistance remains and the stress strain curve falls off rapidly. The marl, on the other hand, is somewhat granular. When the yield point is reached,

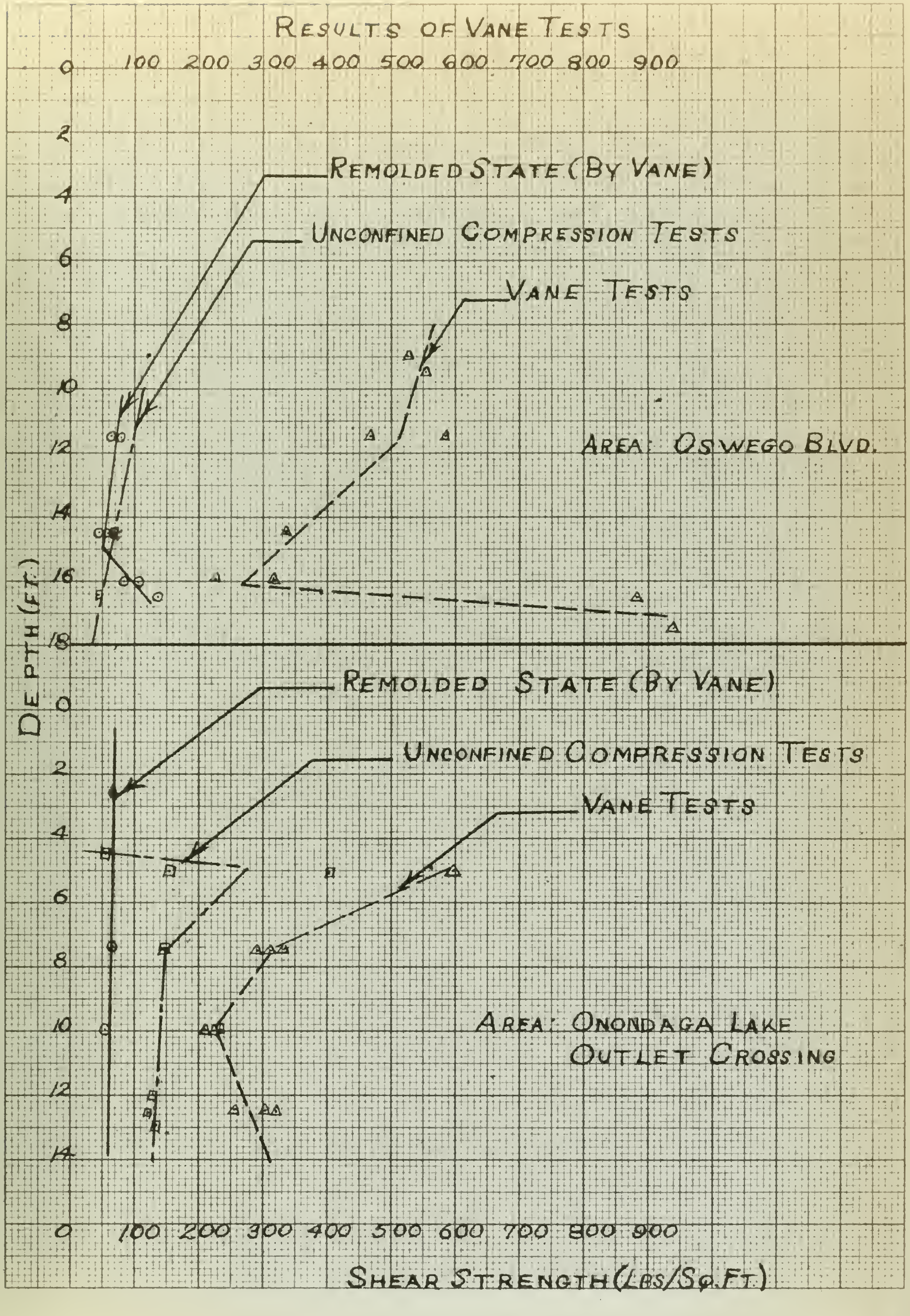
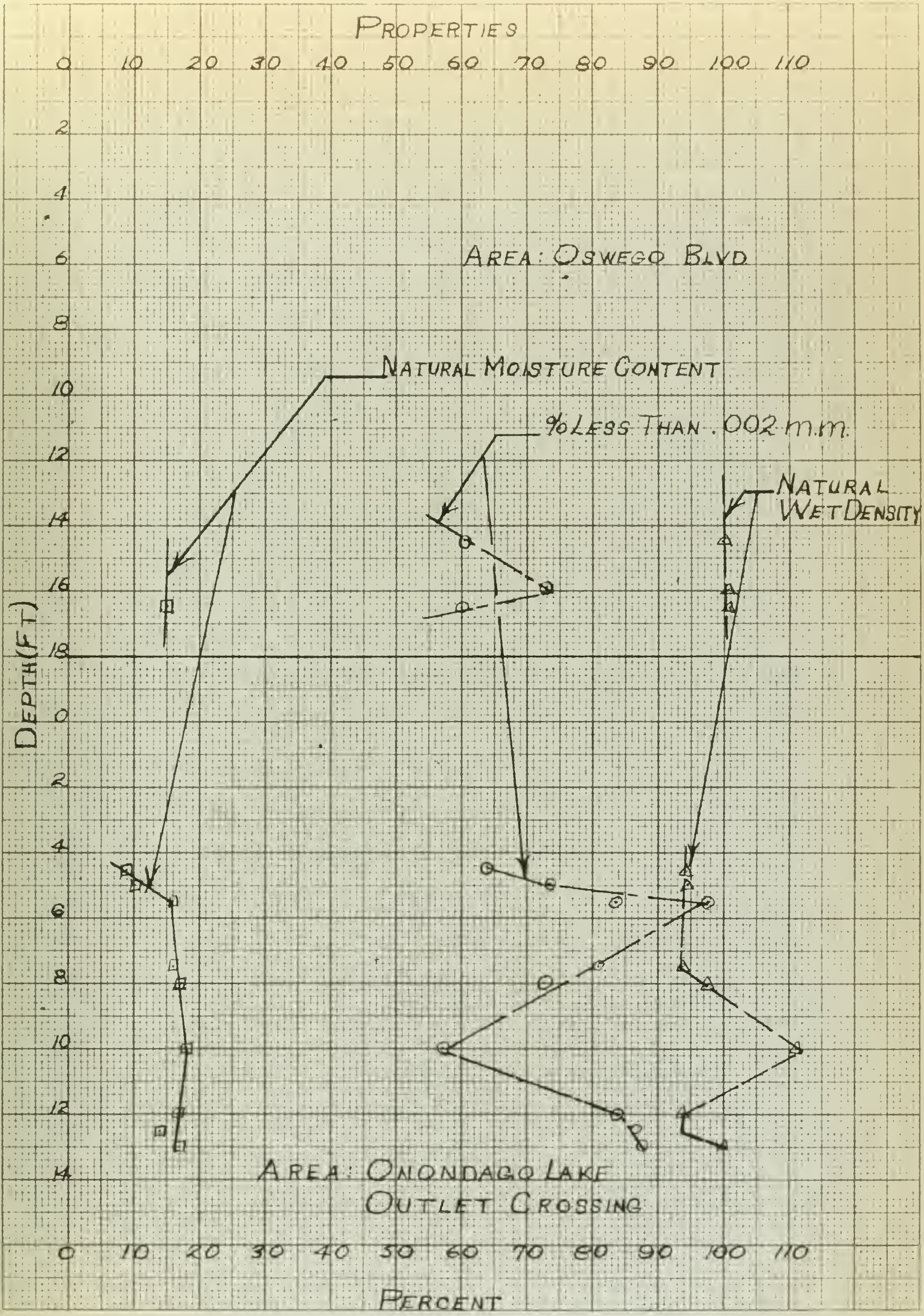

RESULTS OF VANE TESTS
0 100 200 300 400 500 600 700 800 900
REMOLDED STATE (BY VANE)
UNCONFINED COMPRESSION TESTS
VANE TESTS
AREA: OSWEGO BLVD.
DEPTH (FT.)
0 2 4 6 8 10 12 14 16 18
REMOLDED STATE (BY VANE)
UNCONFINED COMPRESSION TESTS
VANE TESTS
AREA: ONONDAGA LAKE OUTLET CROSSING
0 2 4 6 8 10 12 14
0 100 200 300 400 500 600 700 800 900
SHEAR STRENGTH (LBS/SQ. FT.)

FIG. 17



PROPERTIES
0 10 20 30 40 50 60 70 80 90 100 110
AREA: OSWEGO BLVD
NATURAL MOISTURE CONTENT
% LESS THAN .002 m.m.
NATURAL WET DENSITY
DEPTH (FT)
2 4 6 8 10 12 14 16 18
0 2 4 6 8 10 12 14
AREA: ONONDAGO LAKE OUTLET CROSSING
0 10 20 30 40 50 60 70 80 90 100 110
PERCENT

FIG 18

that is, the soil has sheared, a large degree of frictional resistance still exists on the failure surface. This frictional resistance is mainly the tendency for grains to interlock on the failure surface.

(3) Comparison of results. Figures 17 and 18 represent results and properties of material encountered. As was stated in "Preparation and Use of Equipment", only certain typical curves were included in the thesis. Results of all tests, are presented in Figure 17, with the exception of the preliminary operational tests.

It can be seen from Figure 17 that the strength values of the remolded vane tests and the Unconfined Compression (laboratory) test in the marl are in close agreement. This particular fact illustrates the very great advantage of the vane equipment in its ability to obtain as close to an undisturbed shear strength value as is possible. Marl is a material which is very easily disturbed. This fact was realized, but the degree of disturbance was not known. From this data it is possible to determine what degree of disturbance is produced in obtaining a sample by means of a Shelby Tube, transporting it and

handling it during laboratory tests. Since all of the tests were conducted in marl, an average of all values will be used to determine the degree of disturbance. This analysis follows:

Average shear value from unconfined compression equals 122 lbs. per sq. ft.

Average shear value from remolded tests equals 78 lbs. per sq. ft.

Average shear value from vane tests equals 400 lbs. per sq. ft.

Assuming that the vane test is conducted with zero disturbance and that the remolded test represents 100% disturbance, then the per cent or degree of disturbance of the sample is equal to

$$\frac{400 - 122}{400 - 78} \; 100 = \frac{278}{322} \times 100 = 86.4\%$$

The above percentage could be classified as a disturbance factor.

The value of the shear strength is altered by

$$\frac{400 - 122}{400} \times 100 = 69.5\%$$

The remolded shear strength values were calculated as shown in Table 4. In order to make these calculations an assumption was made that the "tare" dial reading to apply to the remolded test was in the same ratio to the remolded reading as the original "tare" (dummy rod) reading was to the vane test. This assumption was necessary since no dummy rod remolded tests were taken.

Different sized vanes were used for different strength soils. It is interesting to note that the 4" vane produced a very smooth stress strain curve as compared with the 3" vane in soils with a shear strength of about 200 lbs./sq.ft. and less. The 4" vane in this very soft material shows no early local failures such as were experienced by the 3" vane. Although a 2" vane was not used by the writers, it is felt that in high strength soils (see "Design") that this size vane would produce equally satisfactory results. The 2" vane may also produce very good results in non cohesive materials.

A comparison of vane tests at the same depth in adjacent holes shows very little deviation in results. This can be seen in Figure 17. This was a further indication to the writers that the equipment as designed,

TABLE FOR CALCULATING REMOLDED SHEAR STRENGTHS

(1) Test No.	(2) Depth (Ft.)	(3) Remolded Dial Reading	(4) Vane Net Dial Reading	(5) Vane Max. Dial Reading	(6) Corrected Remolded Dial Reading $\boxed{(4) \div (5)} \times (3)$	(7) Torsional Moment (In-Lbs)	(8) Remolded Shear Strength (7) x 1.455= Lbs/Ft^2.
S-2	12	54	340	420	43.7	52	75.7
S-3	16	75	180	220	61.3	70	102
S-7	14.5	50	408	688	29.7	38	55.3
S-8	11.5	55	430	720	32.8	41	59.6
S-10	17.5	104	721	890	84.2	93	135.3
S-11	14	35	230	370	21.8	30	43.6
S-13	16	130	565	605	121.2	131	80.6*
S-16	7.5	96	213	348	58.6	67	97.6
S-20	10	90	153	288	47.8	56	81.5

*This test was run with the 4" Vane. This value was therefore obtained by multiplying the torsional moment by 0.614

TABLE - 4

and with the assumptions and theory used would render consistent results. This close comparison shows that it is possible to obtain a very fine calibration for all materials where correct shear strengths can be determined in the laboratory. It was assumed by the writers that the calibration constant to be used in the marl was one. The calibration constant of 1.05 has been used by Skempton for all materials above 40 foot depths.

Figure 18 represents the plot of certain properties of the marl at various depths. This figure allows comparison of these various properties with the appropriate shear strengths obtained by the vane and unconfined compression tests. No studies of this data has been made by the writers due to time limitations. It is felt that with more tests and additional comparisons a more accurate study of trends could be made.

Although the area near Burdett Avenue was used mainly for mechanical operational tests, the material encountered (Albany Clay) and the results obtained allow some comparison and study. The approximate general strength of this clay is known, as it is a soil which prevails in a rather large area throughout Troy and Albany and adjacent lands. Since the material is of such a nature that an unconfined compression test can

produce very satisfactory laboratory results, a comparison with the generally accepted shear strength value and the shear strength obtained by the vane can be made. The generally accepted shear strength value is 500 to 600 lbs./sq.ft. The average value of 2 tests with a 3" vane yields a shear strength value of 564 lbs./sq.ft.

The curves provided in Figures 17 and 18 were plotted from values tabulated in Table 5. and 6.

(B) SUGGESTED FUTURE DEVELOPMENTS AND STUDIES

(1) Equipment. For a detailed list of suggested minor improvements to and development of equipment see "DESIGN, CONCLUSIONS." A list of additional improvements follow:

(a) Jacking mechanism: As was previously stated the jacking method used by the writers consisted of wire rope slings and an automobile bumper jack. Although this method proved satisfactory for the small number of tests taken, the use of a more efficient and less time-consuming method is thought desirable. The jacking system could be designed with the idea in mind of using a screw jack supported on the 4" pipe immediately below the strain plate. The bearing plate should be equipped with a cap for applying a force with

TABLE OF RESULTS

Area: N. Y. S. Thruway, Ontario Section Sub.
3-7, Onondaga Lake Outlet Crossing

Depth Ft.	Natural Moisture Content	% Less Than .002 mm.	Natural Wet Density %	Shear Strengths Lbs./Sq.Ft. Remolded By Vane Test	By Vane Test	By Unconfined Compression
4.5	64	9	94.7		—	51.6
5	73.5	10	94.1		600	153
5.5	97.5	16	83.9		—	402
7.5	81	16	93.8	67	337 291 316	147.5
8	72.7	17	97.8		—	—
10	57.2	18	111	56	228 211 237	—
12	83.6	17	93.7		—	131
12.5	86.5	14	93.8		325 303 254	123.5
13	87.5	17	100		—	133

TABLE - 5 -

TABLE OF RESULTS

Area: N. Y. S. Thruway, Oswego Blvd.
Arterial Syracuse, New York

Depth Ft.	Natural Moisture Content	% Less Than .002 mm.	Natural Wet Density %	Shear Strengths Lbs./Sq.Ft. Remolded By Vane Test	By Vane Test	By Unconfined Compression
9	———	———	———	———	527	———
9.5	———	———	———	———	557	———
11.5	———	———	———	59.6 75.7	582 468	———
14.5	60.4	———	100	43.6 55.3	338	61
16	72.5	———	100.4	102 80.6	226 317	———
16.5	60	15	107.1	135.3	886	40.7
17.5	———	———	———	———	940	———

TABLE - 6-

the screw jack from above (for penetration), and a sling which could be secured to the lower end of the screw for jacking the shaft upward. Adequate clearance above the strain plate should be provided for penetration and removal. Experience of the writers indicated that this clearance should be about 24 inches.

(b) Anchors to base plate: The anchors designed by the writers prevented rotation at the plate, but during jacking they did not prevent lifting. It is, therefore, suggested that other type anchors be investigated, such as, small aircraft tie down anchors.

(c) Placement of stand over 4" (drive pipe) casing: The coupling of the strain plate stand to the drive pipe casing produced several problems such as casing turning. To alleviate this problem it is suggested to provide a larger pipe stand allowing the placement of the base plate and stand over the casing, anchoring the plate and conducting the test in a very similar manner as the tests in a hand auger hole.

(2) Investigations. After accomplishing the above suggested improvements to the equipment developed by the writers, certain additional investigations could be conducted. These suggested studies along with studies

contemplated by the writers but not conducted due to time limitations are listed below:

(a) The effect on the calibration of the vane of blade shapes other than rectangular.

(b) Calibration of the vane (using existing vanes) in a type of soil which will yield laboratory shear strength results that will be more nearly representative of natural conditions. In addition to this, calibration tests in other than highly cohesive materials should be run in order to ascertain the actual diversity of this equipment. From the results obtained by the writers it is felt that the limitation originally stipulated of use in soft, fine grained, cohesive soils can be altered to embrace a much broader scope.

(c) A comparison of strengths by vane and unconfined compression tests versus moisture content, natural wet density, etc.

(d) The feasibility of using vane test results for determining the elastic properties of soil (consolidation and settlement analysis). The writers feel quite strongly that it may be possible to use this equipment for such an analysis (see Fig.4). The Swedish report also indicated this possibility.

(e) The feasibility of using the vane testing equipment for trafficibility studies. Such studies would consist of testing the shear strengths of the soil in situ at very shallow depths to determine what surface treatment might be necessary for light, medium or heavy traffic. (See Bibliography (4)).

(C) CONCLUSIONS

It is felt that the results obtained proved to be satisfactory, and that they tend to show the possible diversity of the equipment. However, more tests are required to fully substantiate this statement. With minor alterations and improvements many tests could be conducted over a relatively short period of time.

CONCLUSIONS

1. The vane testing equipment, as designed and fabricated is considered to be a useful device in determining the shear strength of soils in situ. It is recognized, however, that in order to make practical use of this or similar equipment, i.e. for other than experimental work, it will be necessary to further calibrate it.

2. This equipment can be utilized to determine the actual shear strength of certain types of soil which otherwise cannot be tested in the laboratory as truly undisturbed soil because of unavoidable disturbance through sampling. In addition, it can be used to measure the effects of this disturbance. Such effects were measured by the writers and results thereof included in this thesis.

3. Since the time required to conduct a vane test is considerably less than that necessary for sampling and laboratory tests, vane testing equipment has a definite economic advantage. It is the opinion of the writers that this fact will eventually lead to more thorough foundation investigations.

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